THE DEVELOPMENT OF THE ENDODONTIC COMPLEXITY ASSESSMENT TOOL (E-CAT) FOR ASSESSING ENDODONTIC COMPLEXITY AND ITS PREVALENCE IN GENERAL DENTAL PRACTICE

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ABSTRACT

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Introduction: The need for endodontic treatment in dental care is a well-established in the literature. A substantial perceived need for referring endodontic cases to endodontic specialists has been reported. In order to improve the success rate for endodontic treatment by general dental practitioners (GDPs), the referral of the more complex cases to an experienced endodontist should be made possible in the best interest of the patient. In order to be able to refer such cases appropriately, two requirements need to be satisfied. Firstly, GDPs need to be able to predictably identify the cases with higher complexity and higher risk of adverse outcomes, then treat or refer to the appropriate practitioner. Secondly, there needs to be a sufficient number of endodontic specialists or endodontic workforce with appropriate referral pathways available.

Aims: The aims of this project are therefore twofold. First is to develop a valid and reliable digital assessment tool that can help GDPs assess and classify complex non-surgical root canal treatments (NSRCT). Secondly is to determine the prevalence of endodontic complexity in general dental practice to help assess the level of need for endodontic treatment, training and therefore inform commissioning within the health system.

Methodology: The first part of the research focused on the development of the Endodontic Complexity Assessment Tool (E-CAT). This included a review of the current literature, iterative analysis of the complexity factors and the development of digital software to enhance the tool's efficiency and practicality. Inter-observer and intra-observer reliability studies were conducted with 15 dentists utilising the tool to assess 15 clinical cases and repeating the experiment 9 months later. External validation of the tool was sought with a panel of 35 endodontists to assess

the same 15 cases. The consensus of the panel on the complexity of each case was considered as "gold standard" assessment and was compared to the outcome of achieved by the E-CAT.

For the prevalence study, 30 fully qualified dentists working within general dental practice across the UK were recruited. Each dentist assessed 10-15 consecutive potential endodontic cases as encountered in their day-to-day clinical practice. The data was collected using the online E-CAT. The tool allowed the data to be recorded into a secure database. Information on tooth-related factors, systemic factors, oral diagnosis and patient-related factors was recorded. Three levels of complexity were defined for the analysis; class I (uncomplicated), class II (moderately complicated) and class III (highly complicated). The data was analysed to express period prevalence with a 95% confidence interval using SPSS statistical software.

Results: The E-CAT was successfully developed with a total of 22 complexity criteria; the tool was hosted on a secure university server under the domain of www.e-cat.uk. The inter-user and intra-user reliability was found to be 0.80 and 0.90 respectively. The consensus of the endodontists panel matched to all 15 cases assessed. The inter-examiner correlation of the panel was 0.51. The average time to assess a case was 01:36 minute.

A total of 435 endodontic cases were recorded for the prevalence study. The distribution of complexity over classes I, II and III was 39.8%, 31.9% and 28.3% respectively. History of previous root canal intervention formed 22.9% of the cases encountered. The majority of the cases (64.4%) appeared to have <15 degree root curvature, 30.6% had 15-40 degree curvature and only 4.0% had > 40° curvature. Teeth with existing extra-coronal restorations formed 18.8% of the cases encountered. Radiographically, visible or moderately reduced canal space was reported in 76.9% of the cases, while 20.9% had severely reduced canal space and only 3.2% were perceived to have invisible canal space. History of trauma was encountered in 8.9% of the evaluated cases.

Conclusion: The E-CAT provides an efficient and reliable platform to assess the complexity of NSRCT. The results obtained in the prevalence study provide a good resource and databank for researchers, public health commissioners and academic institutions to access wide range of information concerning the prevalence and distribution of endodontic complexity. The results obtained in this research indicate a possible shortage of endodontic specialist service in the UK, especially within the National Health Service.

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CHAPTER 1 : INTRODUCTION

Endodontics is a branch of dentistry concerned with the cause, diagnosis, prevention and treatment of diseases and injuries of the root canal of the tooth, dental pulp, and the surrounding tissue Torabinejad (2009). It is a recognised dental speciality in the United Kingdom and numerous other countries worldwide. The term endodontics originates from a Greek word; “endo” meaning the “the inside” while “odont” means “tooth”.

In general, endodontic treatment is advisable in situations where a tooth is either already infected, or considered highly susceptible to future infection, as a result of tooth decay, fracture or other forms of trauma. If left untreated, it can result in dental abscesses, pain, swelling and other related complications (Grossman, 1976).

Endodontic therapy or root canal treatment (RCT), usually involve a sequence of clinical procedures to help remove the infected pulp tissue, clean the root canals and seal the decontaminated parts of the tooth from future bacterial invasion. The aim is to preserve the tooth as a functional unit within a functioning dentition. The most common alternative to endodontic treatment is extraction.

The need for endodontic treatment in dental care has been long emphasised in the literature with several studies reporting a substantial need for RCT within the population (Saunders *et al* 1997, de Moor *et al* 2000). A systematic review with a meta-analysis conducted by Pak *et al* in 2012 of numerous worldwide studies included over 300,000 teeth revealed the prevalence of root canal treated teeth to be around 10% of all teeth included in the review. When applied to the general population, the prevalence of endodontically treated teeth was found to be very high, equating to 2 treatments per patient. The authors concluded that billions of teeth are retained through endodontic treatment globally.

The American Dental Association (ADA) 1999 conducted a survey which reported that over 14 million root canal treatments were performed in 1998. General dental practitioners performed about 77% of these treatments. Specialist endodontists performed just over 22%. A more recent US survey was conducted in late 2005-2006 and published in August 2007. Information from the survey was collected using questionnaires and patient care logs. The estimated number for all endodontic procedures was 22.3 million performed annually, and the number of root canal treatments went up to 15.2 million, with a lower number of 72% performed by GDPs and about 28% were performed by endodontists. This trend shows a significant increase in the number of endodontic treatment being performed over this 10 year period. The British Dental Association (BDA) published a report in 2012 titled "Oral healthcare for Older People - 2020 Vision" reporting on the demographics of dental treatment. The population is now living longer, becoming more educated about oral health, the demand for keeping teeth longer is increasing, and subsequently the complexity of saving these teeth is also increasing across all fields of dentistry, including endodontics (BDA, 2012)

No official survey information is available concerning the number of root canal treatments carried out in the UK. However, the dental practice board reported over 1 million root canal fillings performed within the general dental service in the year to March 2004, at an estimated cost of £50.5 million (DPB, 2004). More recently, the Health and Social Care Information Centre in association with the Department of Health published a report on the NHS dental statistics in England for the year 2016/17, reporting the number of endodontic treatments for adults to be around 522,000 (HSCIC, 2017). This figure does not include endodontic treatments carried out in the private sector or secondary care.

Endodontic treatments can vary significantly in their complexity. Some cases can be straightforward and command minimal risk of complication; others can take much longer time and require much higher technical skills and expertise. There are numerous factors which may affect the complexity of RCT. These are discussed in more detail later in this section. Generally, single rooted anterior teeth

with closed root apices and wide uncalcified canals are considered relatively simple to treat (Rosenberg and Goodis, 1992). Accessing the root canal system in those cases is easier due to the relatively uncomplicated root anatomy, making it easier to locate, shape, clean and fill the canals. On the other hand, multi-rooted teeth with very narrow calcified canals, curved roots, previous history of unsuccessful root canal treatments and unusual root anatomy are much more difficult to access, disinfect and fill appropriately. The complexity of each case needs to be assessed individually.

The GDC – "Preparing for Practice" guidelines state that newly qualified dentists should be able to "1.14.9 recognises the risks of non-surgical root canal treatment and how to manage them" and "1.14.10 evaluate the need for more complex treatment and refer accordingly" (GDC, 2015).

Endodontic training forms a vital part of undergraduate training in dentistry. Despite large variations in the teaching approach, dental practitioners are expected to graduate with a working knowledge to be competent in "uncomplicated" endodontic cases (ESE, 2001).

The term complexity itself requires an English definition for the purpose of this research. The word "complexity" stems from "complex", which combines the Latin roots "com" (meaning "together") and plex (meaning "woven"). A complex system is therefore characterised by its inter-dependencies, whereas a complicated system is characterised by its layers. It is seen as subjective topic, as what may be complex to one clinician, may not be complex to another. In addition, what may be complex for one clinician at one point in time may not seem complex for them a year later.

The Association for Dental Education in Europe (ADEE) and the European Society of Endodontology (ESE) undergraduate competency guidelines refer to the graduating European dentist as being competent in the management of 'uncomplicated' anterior and posterior teeth, yet neither clearly defines what is meant by the term uncomplicated (ESE, 2001). This issue cause a wide range of

variation in the level of undergraduate teaching across the teaching establishments in Europe (Qualtrough, 2014).

Numerous postgraduate training pathways have been formulated for those who wish increase their experience and skills in endodontics. The ESE recommends a minimum period of 3 years of further postgraduate training in order to become a certified specialist in endodontics tackling the more "complex" cases (Gulabivala *et al*., 2010). More detailed information is provided within the postgraduate training curriculum on the process, however, a clear definition of the level of complexity is again not available.

There is always an ethical, moral and legal obligation when determining the complexity of any form of dental treatment. In order to improve the chances of success for endodontic treatments in general dental practice, the referral of the more complex cases to an experienced endodontist should be made possible for the best interest of the patient and best treatment outcome (De Cleen *et al*., 1993, Saunders *et al*., 1997, De Moor *et al.*, 2000, Caplan *et al*., 1999). Dietz and Dietz studied the pattern of referrals between American GDPs and endodontists in 1992 and reported that 60% of GDPs selectively choose which cases to treat or refer, 20% never refer their endodontic cases while the other 20% always refer their cases.

The aim of the healthcare system is ultimately to provide the highest possible standard of treatment and place the patient's best interest first. Endodontics is not simply the action of performing root canal treatment. A vital part is arriving at an accurate endodontic diagnosis and good case selection via predictable cost against benefit analysis. In order to achieve that quality of care, a reliable and predictable method of determining when to treat or refer is needed.

More recent surveys indicated a rise in the number of referrals to specialist services. In a Dutch survey 2003, the authors looked into the perceived need of a group of GDPs to refer the more complex endodontic cases to specialist practitioners. The study found 93% of the respondents reporting on the need for a referral pathway (Ree *et al*., 2003b). An American survey carried out at the University of North Carolina in 2010 covering over 1400 dentists in the United States revealed that 96.2% of practicing GDPs refer at least some of their endodontic treatments to a specialist (Curry, 2010). Only 3% were found not referring any cases and 15% reported referring all cases. There are currently no official guidelines to advise general practitioners when to refer a case or to treat it. The general consensus is for dentists to assess their own abilities and tackle each case accordingly.

In order to be able to manage and refer endodontic cases appropriately, two requirements should ideally be satisfied:

- General dental practitioners need to be able to predictably identify cases with higher complexities and decide whether to treat or refer to an appropriate practitioner.
- There needs to be a sufficient number of endodontic specialists or dentists with further advanced skills in endodontics.

The referral pattern discussed earlier can probably be attributed to clinical judgement being a subjective matter. One practitioner may attempt endodontic treatment on a tooth which another would regard as hopeless. A GDP with more experience and enhanced skills may be eager to undertake treatment of endodontic cases which other GDPs would refer to a specialist. In contrast, teeth with a guarded prognosis or difficult endodontic cases may be underestimated because of inadequate preoperative assessment (Messer, 1999). The difficulty here lies in deciding whether to manage the case in general practice or to refer to a specialist should be balanced with the experience and skills of the practitioner. To help addressing this, the use of a standard forms for assessing the difficulty of each

endodontic case was suggested to aid in consistent, systematic assessment of the cases (Messer, 1999).

The decision to do endodontic therapy should not be made in isolation, without comprehensive consideration of the patient related factors, final restoration, and periodontal condition. The challenge is to become more impartial and objective in the decision making by developing a methodical approach to the assessment of endodontic cases, providing a realistic prognosis and ensuring that the treatment is suitable for the patient.

The use of a standardised assessment tool provides a systematic approach to case assessment and help eliminating the subjectivity that may lead to less compromised outcomes (Caplan *et al*., 1999). The advantages of such tools are thought to having greater consistency in assessing difficulty and the ability to document the assessed degree of difficulty. Consequently, a more objective decision on whether to treat or refer the case should help reduce the risk of being confronted with unexpected problems that may seriously compromise the final result.

From a public health point of view, there have been no studies conducted to determine the prevalence of complex endodontic cases in the population or the level of complexity and degree of expertise required. This makes it very difficult to estimate the number endodontic specialists required within the health system.

In 2009, an independent review of the NHS dental services in England led by Professor Steele was published (Steele *et al*., 2009). The report provided a comprehensive overview of the problems with the current arrangements from the points of view of patients, the profession and the NHS. The recommendations made were pointing towards a reform of the system to provide better quality treatments rather than concentrating on numbers and output. A few pilot schemes have been trialled

over the last few years attempting to provide more efficient delegation of resources. Further publications (DOH, 2012, DOH, 2014) provided updates on these pilots and reported growing interest in favour of reforming the dental care provision into three levels of care, 1, 2 and 3. It is proposed that level 1 can be carried out by GDPs who have no further post graduate training, level 2 by GDPs with "additional competencies and enhanced skills" and level 3 by "specialist services". The degree of complexity of endodontic treatment increases from level 1 to 3. However, the reports debate the issue of defining the boundaries of those levels and whether the current health system has enough qualified dentists with expertise for each level.

Being able to classify endodontic treatment complexity into different levels predictably and reliably may help in facilitating this delegation of care levels, whilst identifying the prevalence of each level in general practice may help indicate the number of practitioners required in each category.

CHAPTER 2 : LITERATURE REVIEW

Several tools have been formulated by different bodies to enable dentists to classify which cases are straightforward and within "recently qualified" dental practitioner range and the ones that are more difficult and may require further endodontic training and experience (Ree *et al*., 2003a, AAE, 2005a, Falcon *et al*., 2001). Most assessment forms are designed to aid a more systematic and comprehensive approach to this process. The particular dilemma of difficulty and risk assessment in endodontics has been addressed in the literature in several studies formulating assessment tools which will be discussed in this part of the research. The literature appears to have several research articles evaluating the usefulness of the assessment tool determining the complexity of each endodontic case. A recurrent theme in most of those studies can be noticed. There appears to be little research looking into the validity of those tools and the criteria determining the level of difficulty.

Rosenburg and Goodis from the University of California at San Francisco (UCSF) reported in 1992 in the ADA Journal on the topic of endodontic referrals. Case selection was discussed in details. The authors described a systematic approach of assessing cases for GDPs in an effort to avoid a variety of iatrogenic damage and suboptimal treatment results. The UCSF Endodontic Case Selection provided simple means of determining the complexity of endodontic cases. Each consideration was categorised as complicated, moderately complicated or uncomplicated. Based on the result of the categorisation, GDPs can assess whether a case should be treated or referred to an endodontist. This tool was mainly based on experts' opinion rather than scientific research. The tool appears to have inspired other bodies to develop similar more comprehensive tools which are discussed later. This form currently seems outdated and not widely used probably due to the availability of the more recent forms.

The Canadian Academy of Endodontics (CAE) put together a case difficulty assessment form in 1998. The tool represented a combination of several assessment tools widely used by several dental schools

in Canada at the time. A copy of the form can be found in appendix 7.1.1. Those protocols proved to be valuable, both for teaching and instilling clinical judgment. This form took the shape of thirteen contributing factors that involved the patient, the tooth, and the dental history. Three risk groups were defined, average risk, high risk, and very high risk, which corresponds to class I, II and III respectively. Each contributing factor carried an option to fit those groups where applicable. The average risk group was given the value of 1 unit; the high risk was given a value of 2 units, whilst the very high risk group carried a value of 5 units. There was no clear evidence-based explanation given as to why those points corresponded to each classification. Users of this tool were asked to systematically go through the list and tick each option, then add up all the points to achieve a total sum. The sum then determines the degree of the difficulty or risk. If the total sum added up to be of 15 to 17 units, the case is deemed to be Class I. Class II is given to the range from 18 to 25 units. Any case that exceeds 25 units is classified as Class III difficulty assessment group. This form was found to be user-friendly and widely used in Canadian dental schools and to a lesser extent by Canadian GDPs (CAE, 1998). No attempt has been made to validate this system despite its wide use.

The American Association of Endodontists (AAE) formulated a case difficulty assessment form in 1999 designed for use in endodontic curricula adapting the CAE form. This categorised conditions relevant to endodontic treatments on a non-point based scale. The system was based on several evidence based articles and publication which supported the classification of each difficulty. It attempted to make case selection more consistent, more efficient and easier to document. It also aimed to help dentists with referral decision making and clinical record keeping. A copy of this form is attached in appendix 7.1.2 of this research.

The form also listed conditions which are considered potential risk factors that may complicate treatment and adversely affect the outcome. Risk factors are conveyed to reduce the chance of providing an unpredictable outcome. In this original form, there was no point value attached to any of

the conditions listed, probably in an attempt to avoid assigning points without having the evidence base explanation behind it. The AAECAF was more proactive than the CAE form in attempting to provide more evidence base references to some of the categories that can affect the treatment, however, no real attempt was made to validate this form or assess its reliability.

Nonetheless, this form is speculated to be the most widely known worldwide probably due to the influence of the AAE internationally rather than its practicality (Messer, 1999).

The overall assessment enables dentists to assign a level of difficulty to a particular case. The general outline is similar to the Canadian form in categories and classification; with the three classes of difficulty, minimal, moderate and high. The AAE recommends minimal difficulty cases have predictable outcome if treated by limited expertise practitioner. For higher difficulties the AAE states that a specialist with more clinical experience should treat the case to ensure a predictable outcome.

In 2005, the AAE revisited their difficulty assessment form and added an “educational guide” for the use of the AAE existing form with minor modifications. It was aimed to assist clinical teachers and students in the evaluation and decision-making related to endodontic cases. The intention was for the guidelines to provide a more objective evaluation tool to use in assessing the difficulty and assist in the decision whether to refer or treat. The points and score system was again introduced here in a very similar manner to the previous tools, carrying 1 point for “minimal difficulty”, 2 points for “moderate” and 5 points for “high”. The distinction was made here for the use of this scoring purely for dental students and not recommending it for clinical practice. No justification was made as why this could not be used with GDPs, but the assumption is this could be too time consuming or requires more guidance.

Three ranges were recommended in guiding the decision to refer or treat. When the sum was less than 20 points, it was suggested that junior students may treat. For 20 – 40 points, a more experienced

dental student may treat with very close specialist supervision, or refer to a post-graduate student or endodontist. Above 40 points cases were not recommended as suitable to be treated by an undergraduate student, and should be referred to a specialist in endodontics.

Research carried out at the University of California (Curry, 2010) was designed to assess the effectiveness of the AAE difficulty assessment form in determining whether GDPs would treat or refer a case and the prevalence of its use. 1,434 US dentists completed an electronic survey addressing several aspects related to the use of tool and the pattern of referral. Respondents reported 30.5% of the contributing factors and conditions present on the AAE form were "mostly" important to dentists when deciding to treat or refer an endodontic case. The study did not address a point value system and recommended further research into the validity of the topic. The authors did however suggest that points-based systems may allow a more uniform determination of the difficulty. It was speculated that dentists will have different educational philosophy, experience, and confidence regarding endodontic treatments. Consequently, there will be differences between determining whether to treat or refer. A point based system may help reducing these issues and allow the form to be more reproducible and reliable.

The author also discussed that the comprehensiveness of the AAE may itself be its downfall. They reported that the convoluted information, the length of time it takes to complete and the complexity are likely to be the reason behind the dentists consequently deciding to forego the usage of this form.

Another method of classifying the complexity in restorative dentistry has been described in the Index of Restorative Dental Treatment Need, RIOTN (Falcon *et al*., 2001). The RIOTN complexity index for endodontic treatment outlined the complexity in three levels, described as complexity 1, 2 and 3. This index was aiming to provide a very simple and quick approach to classification. In the process of simplifying this tool the authors seem to have eliminated important factors to be taken in

consideration in endodontic treatments. Factors not considered in the RIOTN index included patient factors, medical history, retreatment specific consideration, trauma and other factors which both the AAE and CAE implemented within their tools.

Muthukrishnan *et al* conducted a study in 2006 to evaluate the reproducibility of the RIOTN when applied to endodontic cases. The RIOTN was used to assess all cases referred for a period of one year in a UK dental hospital. The investigation was led by a restorative consultant and a vocational trainee who was trained for six months to randomly analyse selected cases. The examiners inter-observer agreements were analysed with weighted Kappa analysis. The reproducibility was found to be moderate to poor. It was concluded that the tool was easy to use but incomplete due to the lack of the contributing factors mentioned above. The authors suggested the RIOTN may be used as a valuable tool in risk management or to select suitable cases of endodontic treatment for undergraduate students, but questioned its suitability for general practice.

In 2003, Ree *et al*. published research assessing the usefulness of two case assessment forms among Dutch dentists (figures 5 and 6 in the appendix). The Dutch Endodontic Treatment Index (DETI) and the Endodontic Treatment Classification (ETC) were designed. The DETI is a very simple 2 outcome index which lists 15 conditions. If none of them is met, the case is deemed of straightforward difficulty; if any is met then a full ETC assessment form is to be followed. The ETC form is yet again very similar to the Canadian assessment form with a few minor modifications. The authors of the ETC decided to omit the criterion of whether it is possible to place a stable clamp for isolation as this was thought to render the tooth unrestorable.

The authors also added three of other criteria to the form: (i) the presence of a “composite” core within the pulp chamber possessing higher difficulty, (ii) the presence of iatrogenic incidences such as ledges and apical transportation, and finally (iii) the presence of silver cone sectional obturation. The

ETC authors also expanded the numbers of criteria and tooth considerations which resulted in the case automatically belonging to class III classification.

The ETC adopted a similar approach to the CAE form, contributing factors where defined into three groups, the sum of all criteria with corresponding scoring of 1, 2 or 5 is added up to give an indication of the difficulty or "risk" of the case. The authors used different terms to classify the three levels, average, high and very high risk. A survey was formulated and distributed with the two case assessment forms that questioned the clarity, ease of use, and usefulness of each case assessment form. The respondents agreed with the authors in determining the degree of complexity in 13 out of 15 cases. Despite the increased complexity of using the ETC, 91% of the participants indicated that the form was helpful. It was concluded that case assessment difficulty forms were useful in determining the complexity of endodontic cases. As a result, these forms could assist in determining the need for referral to the endodontic specialist. The participants also reported however that there is a need to simplify the ETC and attempt to improve its usability and sensitivity.

2.1 Factors influencing endodontic treatment complexity; an evidence based approach

As can be seen from the previous findings, the assessment tools reviewed in the existing endodontic literature appeared to lack the evidence based approach in their development. Collating the current available evidence to develop a tool that is based on scientific grounds is likely to be valid and credible.

A widespread literature search was conducted to identify the complexities in endodontic treatment. The MEDLINE (OVID) database, (PUBMED) database, the EMBASE database, the Cochrane Central Register of Controlled Trials (CENTRAL), Scopus, Web of Knowledge, Google-Scholar databases, and peer-reviewed published text-books were electronically searched for available data. Databases were searched from 1945 up to and including December 2017, using different combinations of the key words in the table below. English and English-translated publications were included.

Search keywords

- Endodontics
- Complexity, complex, complicated, complication, uncomplicated
- Difficult, difficulty, challenges
- Root canal treatment, retreatment
- Root canal therapy
- Risk assessment, evaluation, valuation, determination
- Non-surgical endodontics, surgical endodontics

The following section will cover a literature review and an evidence based approach to the assessment factors reported to have an influence on the complexity or adverse outcomes of endodontic treatments. For ease of presentation and discussion, the results of the search were grouped into 13

categories presented in no particular order. Based on the results of this search, these results formed the basis of the methodology described later in chapter 3 of this thesis.

2.1.1 Patient related factors

A review of the most common patient related factors which had possible influence on the complexity and outcome of endodontic treatment identified medical history, mouth opening, and physical limitations to be associated with complex endodontic treatment and present a higher risk of adverse outcomes.

In relation to the medical history, several conditions were reported to require extra precaution in relation to dental treatments in general (Eliav, 2012). The most relevant of those were allergies, unstable cardiovascular disease, haematological disorders, immune deficiencies or patients taking medications such as corticosteroids or anticoagulant that could interfere with intended prescriptions. Aside from ASA IV or V, no specific medical conditions mentioned in the literature were shown to specifically contra-indicate endodontic treatment (Daabiss, 2011).

Despite their rarity, allergy to local anaesthetics or vasoconstrictor intolerance is thought to increase the complexity of endodontic treatments due to the possible high risk of discomfort to the patient (Tomoyasu *et al*., 2011). Root canal therapy may be possible without local anaesthetics in non-vital or root canal retreatment cases (Thomas, 2015, Castellucci and West, 2009), however, extra precautions need to be taken to keep the instruments within the root canal system and avoid any iatrogenic damage. Good knowledge and extensive experience of root canal therapy is recommended in those cases.

Patients with active or history of head and neck cancer, IV bisphosphonate and haemophilia were also shown to be at to further complicate endodontic treatment (Dudeja *et al*., 2014, Kumar and Abrol, 2007, Kalra and Jain, 2013). The risk associated with osteonecrosis and excessive bleeding in this group of patients is well documented in the literature (Nase and Suzuki, 2006, Epstein *et al*., 1997). A case-

series presented by (Katz, 2005) demonstrated the importance of careful endodontic approach when tackling these cases. Specific recommendations were made in relation to applying the rubber dam, avoidance of over instrumentation, perforations and delayed healing times. This complexity would in turn risk a higher chance of unsatisfactory outcome. In addition, due to the high risk of complications associated with dental extractions for those patients, achieving the highest chance of favourable outcome is particularly more important in these cases. Trained specialists or experienced clinicians may reduce this risk by having access to micro-instruments and being more efficient in completing the procedure.

Poorly controlled epilepsy may potentially increase the treatment difficulty of a patient owing to the possibility of intra-appointment epileptic fits (Joshi *et al*., 2013).

Other patient related complexity risk factors were reported to be patients' physical limitations, such as limited mouth opening, inability to recline, anxiety and cooperation level (Davis, 2013, Greig and Sweeney, 2013, Eliav, 2012). Medical disorders such as rheumatoid arthritis and other systemic diseases may influence the difficulty of patient management(Grover *et al*., 2011) in relation to mouth opening and lying patient flat. The more severe those medical factors are, the more complex any form of dental treatment is, including endodontic treatment (Murray, 2015).

2.1.2 Tooth position and angulation

The position of the tooth in the arch, whether it is anterior, premolar, molar or third molar, in addition to the angulation (tilting or rotation) of the tooth were factors found to be related to the complexity of endodontic treatment (Mohammadi *et al*., 2015, Zelikow *et al*., 2008, Sidow *et al*., 2000). Those factors are mostly related to the accessibility of the tooth being treated and the ability to visualise the root canal anatomy without the need for further magnification or lighting. From that point of view, anterior teeth are less likely to encounter accessibility issues, while a third molar is reported to be much more challenging. The anatomy of those teeth may also vary but they are related to have variable degrees of variation (Vertucci, 2005), however, this subject is addressed in pulp canal morphology related factors.

Moderate or severe tooth rotation or tilting as a result of crowding or atypical orthodontic movement may also confuse the clinician further when attempting to access the pulp system. This is particularly more relevant in the event of that tooth being crowned or having a large restoration masking the original anatomy, where higher risk of perforation or iatrogenic removal of sound tooth tissue is more likely (Nayak and Singh, 2013, Darcey *et al*., 2015). Surprisingly, no evidence was found reporting on variation in complexity relating to the tooth position being in the upper or lower arches.

2.1.3 Pre-treatment to commencing endodontic treatment

It is common for endodontic cases to present with several issues that require attention prior to the commencement of endodontic treatment (Castellucci and West, 2009). Many endodontically involved teeth are carious or heavily broken down. Some involve deep fractures, subgingival proximal caries or defective margins. The need for appropriate isolation of the tooth during endodontic treatment requires the use of dental dam (Lin *et al*., 2014). Adequate isolation can only be achieved when the portion of the tooth to be clamped is in a reliable condition. Failure to adequately pre-treat a tooth can result in contamination of the root canal system, clamp disengagement or loss of reference points (Castellucci and West, 2009). Pre-treatment requires extra effort on the part of the treating clinician and added expense to the patient. In order to consider any tooth for endodontic treatment, it should first be determined if it is restorable. The removal of crowns or other extra-coronal restorations prior to commencing endodontic treatment where possible has been recommended in the literature (Whitworth *et al*., 2002, Abbott, 2004, Gorman *et al*., 2016).

In some cases, caries, fractures or defective restorations are sub-gingival. Teeth with caries just below the gingival crest can occasionally be treated by judicious use of electrosurgery or gingivoplasty where hyperplastic or excessive gingival tissue is removed to allow placement of a dental dam clamp. Deep margin elevation is another technique been described to tackle such challenges, but reported to be complex in nature itself (Juloski *et al*., 2017).

Sometimes a tooth will be heavily broken down so that insufficient solid tooth remains to use a dental dam clamp and other extensive treatment of the remaining tooth structure may be required. On other occasions the clamp can be placed, but the post-operative fragility of the remaining tooth poses a serious risk of fracture, leading to loss of a reference cusp during treatment which can mean inaccurate working lengths. In those cases, reinforcement of the tooth is necessary. In severe cases, such as those with those that require osseous recontouring or apical repositioning (e.g. surgical crown lengthening), the patient may require referral to a Periodontist or suitably trained clinician prior to initiating endodontic treatment.

2.1.4 Radiography related factors

Radiographs form an integral part of the endodontic treatment. It is widely accepted that at least one pre-operative and one post-operative radiograph is taken for endodontic treatments (Carrotte, 2005). The angulation of the X-ray beam in relation to the teeth and film can help diagnosis and treatment by producing images which provide additional information not always visible on radiographs taken with standard angulations. Although the use of radiographic techniques increases the diagnostic yield of films, several complications are reported which may impede the use of standard periapical radiographs (Fava and Dummer, 1997). Factors reported include those with severe gag reflex, narrow or low palatal vault or High floor of mouth and hard to solve superimposed anatomical structures.

More recently, the use of cone beam CT scans have revolutionised the amount of information which could be gathered to help treatment planning endodontic treatments. However, the prescription and interpretation of CBCT scans are generally still limited to dentists with further training or as part of postgraduate or specialist training programmes, and therefore expected to be used only in the higher complexity cases where their use may affect the treatment plan proposed (Patel *et al*., 2009, Patel *et al*., 2010).

2.1.5 Diagnostic complexities

Endodontic diagnosis is the basis of successful endodontic treatment. It has been described as a puzzle in the literature (Schweitzer, 2009) , where the pieces must be gathered and pieced together prior to the clinician seeing the complete picture.

Achieving an accurate endodontic diagnosis can sometimes increase the complexity of the treatment being proposed. In the majority of cases endodontic diagnosis can be straightforward and relates to the signs and symptoms clinically encountered. In other cases clinicians can apply some further investigations such as sensibility testing and parallax imaging differentiating the tooth causing the signs or symptoms presented (Rosenberg *et al*., 2009). In some cases however, the signs and symptoms presented to the clinician may be particularly confusing e.g. fractured tooth syndrome or atypical or non-odontogenic facial pain, which may increase the risk of complexity or adverse outcomes if treated without specialised knowledge (Newton *et al*., 2009) . Furthermore, access and knowledge of further imaging techniques such as CBCT may also be required in cases with complex endodontic diagnosis and management (Ee *et al*., 2014). Those factors should be considered prior to any endodontic treatment.

2.1.6 Pulp and root canal morphology factors

It is not surprising that numerous publications are found reporting on the role of atypical pulp and root canal morphology associated with increased complexity of non-surgical root canal treatments. These include increased number of root canals, for example anterior teeth or lower premolars with 2 or more canals (Zhang *et al*., 2017), premolar with 3 or more canals (Sathyanarayanan *et al*., 2017), molars with 4 or more canals (Vertucci, 2005, Acharya *et al*., 2013). Due to the relatively lower prevalence of those variations, and the difficulty visualising them without microscope magnifications, those cases are usually found more complex to manage and are best treated with more experienced endodontists.

Other complex root canal morphology included very long tooth with estimated working length> 30mm (Vargo and Hartwell, 1992, Abiodun-Solanke *et al*., 2013, Vertucci, 2005), dens invaginatus or fusion (Gallacher *et al*., 2016, Alani and Bishop, 2008, Bishop and Alani, 2008), taurodontism (Nazari and

MirMotalebi, 2006, Durr *et al*., 1980) and dentinogenesis imperfecta (Pettiette *et al*., 1999, Bhandari and Pannu, 2008). Amelogenesis imperfecta cases were found more difficult to restore in terms of the patient management overall, but no specific complexity was reported in relation to endodontic treatment. As with the variations mentioned above, these dental anomalies are also less prevalent and hence further training in their management is required; they are reported to have a higher risk of resulting in adverse outcomes, and are more complex to access, shape, clean and obturate.

Finally, atypical root developments such as C-shape (Fan et al., 2004, Martins et al., 2013) and S-shape roots (Sakkir et al., 2014, Machado et al., 2014a) were also implicated with higher complexity. S-shape canals were reported to be more complex to negotiate and shape with high risk of iatrogenic damage such as separated instruments and ledging, while C-shape canals were more challenging to clean appropriately and obturate.

2.1.7 Canal sclerosis and radiographic visibility

Significant number of publications reported on the complex nature of managing sclerotic canals, especially with previous history of tooth trauma or in elderly patients (Schilder, 1974, Allen and Whitworth, 2004). Preoperatively, the level of canal sclerosis is usually assessed by radiographic means prior to commencing treatment. The pulp chambers may be sclerosed or contain large pulp stones and the root canals may be so narrow that even when located they are difficult to negotiate.

One classic publication (Molven, 1973) first described three types of root canal visibility on the radiographs into three categories; canal visible in the whole length of the root, part of the root canal visible and root canal is invisible. More recent publications followed similar approach of classifying them into clearly visible, moderately and severely reduced pulp chamber and finally completely invisible canals (Machado *et al*., 2014b, McCabe and Dummer, 2012).

Interestingly, radiographs of teeth showing apparent total canal obliteration can be deceptive. A study by (Cvek et al., 1982)) attempted to locate and negotiate canals which were not visible on the pre-operative radiographs. In 54 incisors with periapical lesions, the canal was located and treated in all but one of them. Despite the radiographic quality being significantly improved over the last 30 years, radiographic visibility of canal is still not sensitive enough to be 100% accurate (Ki Wei *et al*., 2013). The pre-operative radiograph can still provide a useful reference as to the size, curvature and position of the root canals in relation to the pulp chamber. It is concluded that despite the issue with its sensitivity, generally speaking, the more visible the canal radiographically, the lower the risk of encountering difficulty locating and negotiating those canals. This topic is further debated within the discussion of chapter 3.

2.1.8 Root curvature

One of the most reported factors affecting complexity encountered in this search is the management of curved canals (Ansari and Maria, 2012). Various curves are present along the length of the canal and the preparation of these curved root canals can become challenging. Curved canals may also restrict the chemical irrigation and mechanical preparation or may lead to some iatrogenic damage affecting the prognosis (Peters, 2004). Preoperative assessment of the curvature is necessary so that the degree of curvature and radius of the root canals are assessed. Several techniques are described in the literature to assess root curvature, these include (Schneider, 1971), Weine, Lutein's (Luiten *et al*., 1995) and Cunningham's (Sonntag *et al*., 2005) methods of evaluating root curvature as summarised in Balani *et al*., (2015). Some authors also looked into considering the radius of the curve rather than the angle (Estrela *et al*., 2008). Those methods were all considered for the purpose of the study. Schneider technique was found to be the most familiar and easier to follow despite the limitations of subjectvitiy associated with it (Gu *et al*., 2003, Gunday *et al*., 2005).

A trend of progression can be seen in the literature description of mild, moderate and severe root curvature as technology advances. The canal was originally classified as straight (if the angle was 5° or less), moderate (10-20°), or having severe curvature (>20°) (Schilder, 1974). This description seems to shift with the advancement of the NiTi endodontic files flexibility, with the AAE (AAE, 2005a) and Dutch (Ree *et al*., 2003a) systems describing mild as <10°, moderate as 10-30° and severe as >30°. The RIOTN (Falcon *et al*., 2001) system chose to have the angles set at <15°, moderate as 15-40° and severe as >40°. In vitro research looking into different file systems with simulated curvature running from 20-40° seems to support the 40° curvature as threshold for higher risk of file fractures or iatrogenic incidents with 60° posing highest risk (Capar *et al*., 2014, Saber *et al*., 2013).

A recent study looking at the inter-examiner variation when interpreting periapical radiographs showed significant variation and inaccuracy when dentists were asked to visually assess root canal curvature (Faraj and Boutsioukis, 2017). Nonetheless, accepting the limitations, as with radiographic visibility of sclerotic canals, it can still be concluded that the less the perceived curvature of the root is the lower the risk of encountering difficulty negotiating and shaping the canals. Nonetheless, clinicians need to exercise care due to the relatively low sensitivity of the radiographic findings.

2.1.9 Presence of direct and indirect restorations related risk factors

The review in this area yielded few factors which may affect the complexity of endodontic treatment. This included the presence of large direct restorations that mask original crown morphology, crowns, bridges, onlays or other forms of indirect restorations. Attempting an endodontic access through such restorations and restoring the access opening rather than removing the existing restorations is problematic (Abbott, 2004). Even when the restoration may appear to be clinically and radiographically sound, upon access and further inspection clinically, even in such radiographically acceptable crowns, it is common to find caries, cracks, and unset restorative materials that previously were not visualised. In addition, especially in extra-coronal restorations

that cover the entire chamber of the tooth, it is not at all uncommon to find previously unidentified small posts and previous endodontic access (Mounce, 2009).

Judging the quality of crown margin integrity on a radiograph is also challenging. Radiographs that show excellent crown margins or do not show caries may be grossly deficient depending on radiograph angulation or quality of development. Even though it may not be seen as practical (mostly due to financial reasons), the ideal endodontic access is one made after a previous crown has been removed and the tooth carefully examined under a dental microscope for the issues mentioned earlier (Abbott, 2004).

In certain scenarios, for various reasons it may not possible to remove the crown at least in the short term. In those cases, the treating clinician will need to take radiographs from more than one angle and a complete history (general, dental and of the tooth) and evaluate pulpal status (Mounce, 2009). This may include evaluating the tooth response to percussion, palpation, mobility and probing depths as well as to cold.

The greatest level of visualisation and magnification must be used to visually inspect the inside of the tooth should the restoration remain. Such an inspection should seek to identify any areas where the crown is inadequate (especially when such marginal discrepancies are not visualized outside the tooth) as well as a visual inspection for all manner of unfavourable events (Trautmann *et al*., 2000). In addition, there is a higher risk of perforations associated with endodontic accesses through existing extra-coronal restorations (Tsesis and Fuss, 2006). This is likely to be due to the loss of anatomical structures which usually help guiding the endodontic access, or to the difficulty judging the inclination or rotation of the original tooth underneath. For the reasons mentioned above, the presence of extra-coronal restoration is seen result in more complex endodontic treatment.

2.1.10 Previous endodontic treatment related risk factors

The search in this area returned numerous factors which could influence the complexity of non-surgical root canal retreatment (Gilbert *et al*., 2010, Carrotte, 2004).

To start with, the type of material used to obturate the canals was one of the frequently reported factors associated with the complexity of retreatment (ØRstavik, 2005). This may include gutta-percha (Good and McCammon, 2012), silver or metal cones (Plack and Vire, 1984), root canal obturating pastes and cements (Tomson *et al*., 2014, Al-Haddad and Che Ab Aziz, 2016), carrier based obturation (e.g. Thermafil) (Beasley *et al*., 2013). Generally, conventional gutta-percha is considered easier to remove than other non-conventional materials. The use of pastes and hard setting cements, including the more modern bioceramic cement (Hess *et al*., 2011), is reported to further complicate the re-treatment process.

The quality of the obturation is also expected to affect the complexity of the endodontic treatment. Well obturated, well condensed root canal fillings reaching to within 2mm of the radiographic apex are generally reported to be more difficult to remove compared to root fillings which are short, poorly condensed or being single cones (Gordon, 2005). Overfilled root canal fillings are thought to pose further complexity especially when the overfilling is greater than 2mm in length (Silva *et al*., 2012, Jaikailash *et al*., 2012). The removal of such fillings requires more attention and is ideally done utilising manual techniques and higher magnifications. Higher risk of severing the apical portion and having it extra-apically is expected which may compromise the treatment outcome.

The presences of endodontic cores or posts were also reported to further complicate the retreatment (Castrisos and Abbott, 2002, Dickie and McCrosson, 2014). Amalgam cores were found to pose a risk of complication, but less than that encountered with composite cores, possibly due to the colour and adhesive nature of composite cores (Adegbembo and Watson, 2005). The type, width and length of posts used, in addition to the type of cement used to place them can influence the complexity of the treatment (Rollings *et al*., 2013). The wider, longer and the less tapered the post

placed is, the more complex it is to remove. Generally, posts that are short, more tapered, and those cemented with non-adhesive cement are thought be easier to manage. Direct posts are found to be easier to remove than indirect custom-made posts (Abbott, 2002).

Another complexity factor related to previous endodontic treatments, whether obturated or not, also include the potential presence of iatrogenic damage posing higher risk of difficulty. These may include significantly misaligned previous endodontic access (Haji-Hassani *et al*., 2015), ledges (Jafarzadeh and Abbott, 2007), canal transportation (Mantri *et al*., 2012), perforations (Tsesis and Fuss, 2006) and fractured instruments (Simon *et al*., 2008, McGuigan *et al*., 2013). Managing clinically visible, coronally fractured instruments and perforations was reported to be relatively easier than managing their non-clinically visible and apically positioned equals (Solomonov *et al*., 2014). Nonetheless, most iatrogenic damage is recommended to be managed by more experienced clinicians under high magnification surgical microscope or at least optical loupes.

2.1.11 Root resorption related risk factors

The endodontic management of root resorption was found to be frequently reported as a highly complex and demanding procedure in the literature (Darcey and Qualtrough, 2013a, Fuss *et al*., 2003, Ne *et al*., 1999). Good understanding of the resorption process, including its aetiology, classification and the different management technique is paramount. The management of external and internal resorptions were both reported to be more complex than the management of apical or surface root resorption (Darcey and Qualtrough, 2013b). Diagnoses, assessing the extent of resorption (usually requiring the prescription of CBCT), debriding, shaping, cleaning and obturating the resorption defect are all reported to be challenging and resulting in higher risks of adverse outcomes (Darcey and Qualtrough, 2016).

In addition to internal and external root resorption, apical surface root resorption may cause enough tooth surface loss to result in the loss of the apical constriction resulting in an open apex

(Shabahang, 2013). The management of those cases usually require an apexification procedure, either conventional or through the use of bioceramic or MTA type apical plug which in turn is best done under magnification by an experienced clinician.

2.1.12 History of dentoalveolar trauma

Generally, endodontic cases with a history of dental trauma were reported to be more complex and more challenging to manage due to the higher risk of pulp canal obliteration and root resorption associated with those cases (Moule and Moule, 2007, Ravn, 1982, Zaleckiene *et al*., 2014). In addition, teeth with overt history of root fracture present even higher challenge due to the difficulty ensuring straight canal negotiating and achieving good obturation. The following types of dental trauma were reported to affect the complexity of endodontic treatment; concussion and subluxation (de Cleen, 2002) due to relative risk of pulp canal obliteration and resorption, root fracture, due to negotiation and obturation challenges (Turgut *et al*., 2004), complicated crown fracture of mature teeth which may benefit from vital pulp therapy (Andreasen *et al*., 2002), complicated crown fracture of immature teeth which may require vital pulp therapy or apexification (Beslot-Neveu *et al*., 2011), avulsion or severe luxation due high risk of root resorption (Rosenblatt, 2010).

Teeth with previous history of trauma are therefore at higher risk of encountering complexity during the course of their treatment or resulting in adverse long term outcomes.

2.1.13 Periodontics-Endodontics related risk factors

Periodontal-endodontic lesions present challenges to the clinician regarding diagnosis, treatment planning and prognosis (Rotstein, 2017, Chapple and Lumley, 1999). Aetiological factors including bacteria and viruses, alongside contributing factors, such as root resorptions, trauma, cracks, perforations and dental developmental abnormalities all results in a more complex treatment.

Treatment and prognosis of periodontal-endodontic lesions vary, depending on the correct diagnosis, aetiology and pathogenesis of each specific condition. The factors most associated with complexity are true periodontal-endodontic lesions (Simon *et al*., 1972), tooth mobility (Rotstein and Simon, 2004), fenestrations or dehiscence and root resection or hemi-section expected or already completed (Schmidt *et al*., 2014, Vakalis *et al*., 2005). The presence of those factors is reported to lower the chance of successful outcome and to be more challenging to manage.

2.2 Prevalence of complex endodontic cases and influencing factors

There are several cross-sectional studies describing the prevalence of periapical radiolucency in the population, a surrogate of necrotic pulp disease. In addition, there are other studies looking into the prevalence of root canal treatment within the population. Owing however to the level of complexity being a subjective issue, there does not appear to be any attempt to identify the prevalence of complex treatment or the reasons behind such complexity.

A cross-sectional study completed in the UK (Saunders *et al*., 1997) looking into the prevalence of periapical radiolucency examined full-mouth periapical radiographs from 340 consecutive adult patients attending two Scottish Dental Hospitals for regular examination. The results showed 54% of the patient sample had received at least one RCT. When related to the teeth sample, around 5.6% of the overall examined teeth radiographically had endodontic treatment, and of these, 58.1% had radiographic signs of periapical disease. Understandably, the authors did not attempt to comment on the difficulty range of endodontic treatment on these teeth as this would require pre-knowledge of the status of teeth involved and clinical data. The methodology of this study however may be particularly relevant to this research. Despite most prevalence studies reporting a sample size with large number of teeth included, ranging from 1600 teeth and up to 30,000 teeth, the number of patients sample size is in reality much lower ranging from as little as 70 patients and averaging around 200-300 patients (Pak *et al*., 2012).

An attempt to determine the most common endodontic complexities encountered by GDPs in South Korea was made through a study of referral reasons to endodontic practices (Kim, 2014). This observational study was conducted to investigate the prevalence of different primary reasons for endodontic referrals and the clinical symptoms of the referred cases over a period of 2 years. The study outcome focused more on the symptoms of failed root canal treatment rather than the technical reasons behind the referrals. It was found that the most common referral reasons were

persistent pain and presence of a sinus tract following primary RCT. The most common clinical reasons were found to be canal calcification, broken instruments and posts.

This gap in the knowledge of complexity prevalence within the literature indicated the need for research to provide the data, which may be used in several applications to deduce the level of need for endodontic training and commissioning within the health system.

It is evident that in order to collect such information, there needs to be a way of identifying the relevant complexities first then classifying them, and then a mechanism to gather the information from the population.

Approaching epidemiological and prevalence studies electronically has been reported to be the preferred way in the future in epidemiological studies. Several studies have discussed the potential benefits and disadvantages of web-based surveys and the ongoing developments in the area (van Gelder *et al*., 2010). Conventional methods to gather information from study subjects, including face-to-face, traditional paper and-pencil format questionnaires and telephone interviews are increasingly failing to generate high-standard qualitative results within the financial parameters given. Web-based surveys are now frequently used in marketing research and psychological studies, but their use in epidemiological studies was merely 1% in 2007 (Ekman and Litton, 2007).

There have been a few examples of successful studies conducted using the electronic surveys approach and are already available, including Danish Web-based Pregnancy Planning Study (Mikkelsen *et al*., 2009), the Millennium Cohort Study (Smith *et al*., 2007) and the Nurses and Midwives e-Cohort Study (Turner *et al*., 2009). Those studies succeeded to collect a large sample number through electronic surveys with meaningful results.

Electronic surveys are becoming increasingly more attractive with the advancement of information technology and the availability of electronic devices (Dillman and Smyth, 2007). Pop-up windows combined with visual and audio aids providing additional information may be added to clarify

responding in those surveys, which would have been much more difficult to implement in paper-format questionnaires. Electronic surveys can be programmed to automatically analyse and present the data in a much more user-friendly format. However, the issues with web-based epidemiological studies usually concern practicality and data safety. A study looking into those issues concluded that many of those problems related to the use of web-based questionnaires have been solved, but each case needs to be approached individually (van Gelder *et al*., 2010). One of the most important factors to consider is the design of the questionnaire, its practicality and ease of use.

Electronic epidemiological studies could potentially be considered a complementary alternative mode in the methods of data collection. Further studies and comparisons with the conventional survey techniques should reveal whether they can fulfil these expectations.

2.3 Digitalisation of assessment tools

The use of risk assessment tools is not a new concept to the medical field. However, more recently, the development of a more convenient, time efficient digital forms to simplify their use has been documented across numerous specialities in healthcare. Aside from the efficiency and the simplicity advantages of digitalising the assessment tools, there are significant other benefits for adopting a "paperless" approach to all forms of documentation within the healthcare system. In 2013, the UK Health Secretary Jeremy Hunt reported in an official statement the NHS should go paperless by 2018 in order to generate vast savings for the NHS.

The report on NHS services in England (Steele *et al.*, 2009) itself also made recommendation for all general dental practices to use electronic records and adopt a paperless structure in order to improve the quality of patient records and save valuable time which can then be spent on patients care.

An official government document was also published by the Department of Health and on GOV.UK reporting on a study by Price Waterhouse Coopers reviewing the potential benefits of better use of information technology (Price Waterhouse Coopers, 2013). The study found that measures such as more use of electronic prescribing, text messages for insignificant test results and electronic patient records could save in the order of £4.4 million per annum of NHS money and even more in the long term. It would also facilitate improved care, allowing healthcare personnel to spend more time with patients. The health secretary report suggested a roadmap detailing several targets. This included the adoption of paperless referrals, sending an email rather than a letter when referring a patient to the hospital.

The report itself highlighted a few small trials of interest to this research. In an attempt to increase their clinical effectiveness, the Royal Liverpool and Broadgreen Hospitals Trust trialled a computerised paperless system on its dermatology and haematology departments. This meant that professionals could see letters from clinics, GP referrals, test orders and radiographs on a computer

system. They found that the process could help saving 30 minutes in a three and a half to four hour clinical session. In addition, the Royal National Orthopaedic Hospital conducted a trial of a system that asks patients with spinal surgery to record their progress using an iPad or an online system after being discharged. This freed up around 300 new outpatient appointment slots per consultant per year. Around 95% of participants preferred the new online process to the traditional paper format method. The benefits also include the financial and environmental cost savings on not using wood papers or ink (Davis, 2013).

In view of the above recommendations, the concept of converting existing endodontic difficulty or complexity assessment tools into a digital format becomes a matter of natural and logical evolution. It can be speculated that non-computerised forms would slowly grow out favour and their use will become more alienated on the long term. Creating an electronic version may revive these tools and keep their advantages and benefits within clinicians' reach.

In 2011, a group of young Australian researchers worked together on developing a Computerised Antithrombotic Risk Assessment Tool (CARAT) to optimise the therapy of atrial fibrillation (Bajorek *et al*., 2012). The tool was developed on previously trialled algorithms involving multidisciplinary feedback. The authors created an item of computer software then made it available to clinicians to apply it to the management of patient cases and evaluated the software usability. There was an overall 94% satisfaction reported among the hospital-based clinicians who trailed it, and 85% reporting the usefulness of the software.

Another use of computerised analysis was reported in the assessment of digital clubbing (Finger nail clubbing) in medical patients in Switzerland (Husarik *et al*., 2002). The authors developed a computerised assessment form and combined it with digital photography to help overcome the limitation of subjective clinical assessment. The overall outcome showed the use of computerised analysis to be an easy, fast and inexpensive method for quantifying the condition with good intra and inter observer reliability. It was concluded that the tool may be useful in further cross-sectional

or longitudinal studies of finger morphology and exploited it may become an accepted standard in the diagnosis of digital clubbing.

On the flip side, challenges have been reported when attempting to convert surgical assessment tools to an electronic version. A recent Canadian study (Dudek *et al*., 2015) sought to convert a paper-format assessment tool, the Ottawa Surgical Competency Operating Room Evaluation, to a computerised version for use in three surgical specialties. Nonetheless, as the research progressed, the focus of the study had to be altered as it became necessary to explore the issues of transitioning to a paperless assessment tool rather than reliability. This finding was unexpected as theoretically an electronic tool should reduce the time taken not the reverse.

The study above highlights important findings. It is important to understand that users require the tool to be at least as convenient as its counterpart paper version. Transitioning from a paper-format assessment tool to a computerised one is not necessarily a natural intuitive process. Careful consideration of potential barriers and taking a step back to solve these barriers is essential to achieve the many benefits of electronic assessments mentioned in earlier literature.

2.4 Conclusion

Following the literature research findings presented earlier, the current limitations of the existing assessment tools appear to be the intricacy and the lack of clarity of the contents, in addition to the length of time it takes to fill them and then add the sum up. An advance is thought to be to attempt simplifying those forms or their presentation into a more user-friendly interface and reduce the amount of time required to complete them where possible.

Conducting a wide literature review of the existing evidence reporting on the factors that may affect endodontic treatment complexity proved to be a highly time consuming process. Despite few factors having clear and direct literature links, the majority of the factors evaluated had fewer and lower quality evidence demonstrated by indirect findings of a larger study, case reports, textbooks and narrative publications. Due to the wide range of factors involved, it is unlikely this gap in literature would be filled anytime soon. Aside from complexity being a subjective matter, the perceived benefit of conducting research purely to assess the level of complexity of each factor does not justify the cost required to organise the study. Further analysis to evaluate the tools clinical relevance and external validity may be more beneficial. Adjustment can subsequently be made to fine-tune the relative complexity of each factor.

Academically, the undergraduate competency guidelines by the ADEE and ESE both referred to the newly qualified European dentist as being competent in the management of those 'uncomplicated' non-surgical root canal cases, yet neither guidelines clearly define what is actually meant by uncomplicated. This results in a wide variation in the standards of qualifying dentists due to different interpretation of the term. Utilising the results of the literature review above, combined with the studies conducted in chapter 3 and 4, this thesis will discuss the exact definition of the word in more details in chapter 5 of this document (5.2).

Another substantial gap in the knowledge identified was the lack of any good quality research attempting to validate the existing endodontic complexity assessment forms and tools. Having a more validated tool may give better credibility to them and may attract more users to utilise them.

From a public health point of view, there is a lack of studies conducted to determine the prevalence of complex endodontic cases and the factors leading to their encounter. It is therefore difficult to evaluate the accessibility of endodontic service available and the level of training required within the health system.

2.5 Research Aims

Based on the previous findings, the aims of this research were set to be the following

- To develop a novel, more predictable and evidence based complexity assessment tool utilising the digital advancements
- To evaluate the reliability, validity and practicality of the new tool in comparison to the existing literature
- To provide a more objective definition of the term “uncomplicated” root canal treatment as described by the ESE an ADEE undergraduate curriculum guidelines for Endodontology
- To assess the prevalence of complex root canal treatments in general dental practice in the UK and identify the prevalence and distribution of the specific factors leading to this complexity

CHAPTER 3 : THE DEVELOPMENT OF THE ENDODONTIC COMPLEXITY ASSESSMENT TOOL (E-CAT)

3.1 Introduction and Aims

Assessing endodontic complexity is often seen as a subjective, clinician-dependant and widely variable area. The development of a tool to aid making this process more standardised, more accurate and less subjective is therefore desired to help clinicians identify more complex cases and determine whether to refer or treat (Dietz and Dietz, 1992). Rosenburg and Goodis had highlighted the issues associated with developing an assessment form with the UCSF Endodontic Case Selection Form in 1992 . These were further emphasised when the Canadian Endodontists and the AAE created the Case Difficulty Assessment Forms to assist clinicians in determining the complexity of cases. Ree *el al* in 2003 demonstrated that the use of a systematic means of assessing endodontic cases was helpful when assessing case complexity.

As can be seen in the previous chapters, several endodontic assessment tools have been formulated by different bodies and institutions to enable dentists to classify the complexity of non-surgical root canal treatments. The main tools reported were the Canadian Academy of Endodontics cases assessment form, AAE assessment form, the Dutch endodontic treatment index and endodontic treatment classification in addition to the restorative index of treatment need RIOTN. Most assessment forms are designed provide a more systematic approach to assessing endodontic treatments.

The overall outcome of the literature review commended the comprehensiveness of the Canadian, AAE and the ETC in covering the aspects required to be assessed prior to determining endodontic complexity. On the other hand, criticism was reported regarding the shortfalls of the RCS RIOTN and the short Dutch DETI being too brief. There was no methodological literature reviews reported to scientifically support the criteria included in any of the existing tools. There appears to be several research articles reporting on the usefulness of the assessment tools, but a recurrent theme in most of

those appears to report the little research looking into evidence behind the production process, in addition to the reliability and validity of those tools and the criteria determining the level of complexity.

An outcome of the literature review found the most criticised areas of the existing endodontic assessment tools is the arbitrary allocation of risk or hazard points to relevant endodontic criteria with the lack of scientific basis behind it.

For example, the widely used AAE classification divides complexities into three difficulty levels, minimal, moderate and high. The clinician is advised to review the form following "ticking" the relevant boxes of the criteria and using self-judgement to assess the difficulty level. One high difficulty category selection pushes the case difficulty to high complex. The Dutch ETC gives the value of 1, 2 and 5 points for moderate, high and very high risk criteria. The AAE "educator guide" uses similar values. However, the current literature does not provide scientifically supported justification behind giving any of the criteria these values or what value they should add up to prior to a certain level of complexity being attached to a case.

In order to utilise the information gathered from the literature review and adopt a more scientific methodology to assigning value to each complexity criteria, an iterative development approach was implemented.

Iterative development (from Latin *iterare* 'to repeat') is a combination of both iterative design and incremental build-up model for software development. This well-established approach is widely used in software development (Larman and Basili, 2003).

In 2009, (Srivastava and Hopwood, 2009) described a framework in which qualitative data, which in this instance is the reported endodontic complexities in the literature, can be related into more quantitative data (complexity score, in points) using iterative analysis. The process essentially involves developing a system through repeated cycles (iterative) and in smaller increments at a time

(incremental), allowing the software to take advantage of what was learned during development of earlier cycles of the system. Knowledge comes from both the development process and the application of the tool, where possible key steps in the process start with a simple implementation of a subset of the software requirements and iteratively enhance the evolving versions until the full functional system is implemented. Following each iteration, complexity value modifications were made and new values added as necessary. The relationship between iterations and the increments is an integral part of the overall software development process. The exact value and nature of the increments are specific to each complexity criteria.

Consequently, the aim of this part of the research was the development of an interactive digital tool utilising reported evidence from the literature as reviewed in the chapter 2 earlier. The tool is aimed to help clinicians to assess the endodontic complexity of the non-surgical root canal therapy case they are intending to treat; hence given the title of the Endodontic Complexity Assessment Tool (E-CAT). The objective here was to take into account the positive aspects of the multiple existing tools and incorporate them into a new single product, in addition to applying improvements and new features to address and overcome the drawbacks. In summary, the aim is to establish a tool which is developed utilising an evidence-based approach and ideally needs to be evaluated for its reliability and internal and external validity.

The new tool ideally should overcome the drawbacks of the existing tools, being less-intuitive to use and time consuming. As could be seen from the literature review, when done correctly, digitalising assessment tools proved to provide positive, more practical user interface and can help increasing its efficiency by reducing the overall time required for the assessment.

The research hypothesis was therefore set as “it is possible to develop a digital tool to predictably and reliably identify complex endodontic cases similar to that identified by a group of Endodontist Specialists”. The null hypothesis was the development of such tool is not possible.

3.2 Methodology

3.2.1 Complexity Criteria

A comprehensive literature search was conducted to identify the complexities that can be encountered in endodontic treatment. The MEDLINE (OVID) database, (PUBMED) database, the EMBASE database, the Cochrane Central Register of Controlled Trials (CENTRAL), Scopus, Web of Knowledge, Google-Scholar databases, and peer-reviewed published text-books were electronically searched for available data. Databases were searched from 1945 up to and including October 2017, using different combinations of the key words in the table below. English and English-translated publications were included.

Search keywords

- Endodontics
- Complexity, complex, complicated, complication, uncomplicated
- Difficult, difficulty, challenges
- Root canal treatment, retreatment
- Root canal therapy
- Risk assessment, evaluation, valuation, determination
- Non-surgical endodontics, surgical endodontics

The outcomes of this search are reported in the results section of this chapter.

3.2.2 Iterative development

In this study, a wide range of endodontic cases consisting of 75 pre-assessed real-life clinical cases classified by the researcher and a supervising clinician (Speciality Registrar in Endodontics and GDC registered Specialist Endodontist) were used to calibrate the tool and assigns numerical value to each complexity criteria mentioned above. When disagreement was found, a third specialist in endodontics was consulted and agreement was achieved. All 75 cases were given a complexity class of 1, 2 or 3 (uncomplicated, moderately and highly complicated) following to the completion of treatment. These were treated in a hospital setting. Initially, the arbitrary score of 1, 2 and 5 were given each selected criteria according to its documented complexity (E-CAT ver 2.0). The range for the classes was set to

- less than <20 for uncomplicated cases,
- 20-25 for moderately complicated and;
- >25 for highly complicated cases.

Those figures were based on similar tools available in the literature such as the AAE and the Dutch forms.

Each cycle started in the same order of the 75 cases. When a case was found not to fit the clinical outcome, adjustment to the relevant complexity factor value was made. The case was tested and re-tested to ensure it fits to the new corrected values. Then the iterative cycle started again from the first case to ensure the rest of the cases still follow the perfect fit model.

The first cycle or the iterative analysis started with the arbitrary values of 1, 2 and 5 as suggested by the previous tools. The range of values was changed from 0-10 to allow more flexible iterations. Repeated cycles were then applied to each of the 75 cases over and over until a fitting model was produced. This meant if the tool was used correctly to assess any of the 75 cases, it would result in an outcome matching to that encountered clinically. The number of cycles required and the outcomes of this analysis will be presented in the results section.

3.2.3 Software development

The review of the literature reported one of the significant drawbacks of the existing assessment forms to be time-consuming and less user-friendly. As discussed earlier, building a novel and smart software for an online digital tool was the proposed approach in this study.

The software was developed over two phases. The first phase was completed in collaboration with an MSc computer studies student at The University of Liverpool as part of his MSc project. This was done with simple HTML coding and implemented onto the following website

http://cgi.csc.liv.ac.uk/~m4ll

This first prototype E-CAT (Version 1.0) simply aimed to digitise the Dutch paper forms presented by (Ree *et al*., 2003a) into a user friendly online form which automatically adds up the complexity criteria in the background and generates the answer. The time saving feature was intended to be the automatic sum up and the addition of photo illustration to relevant questions.

Snapshots of this version can be seen in the figures 1 below.

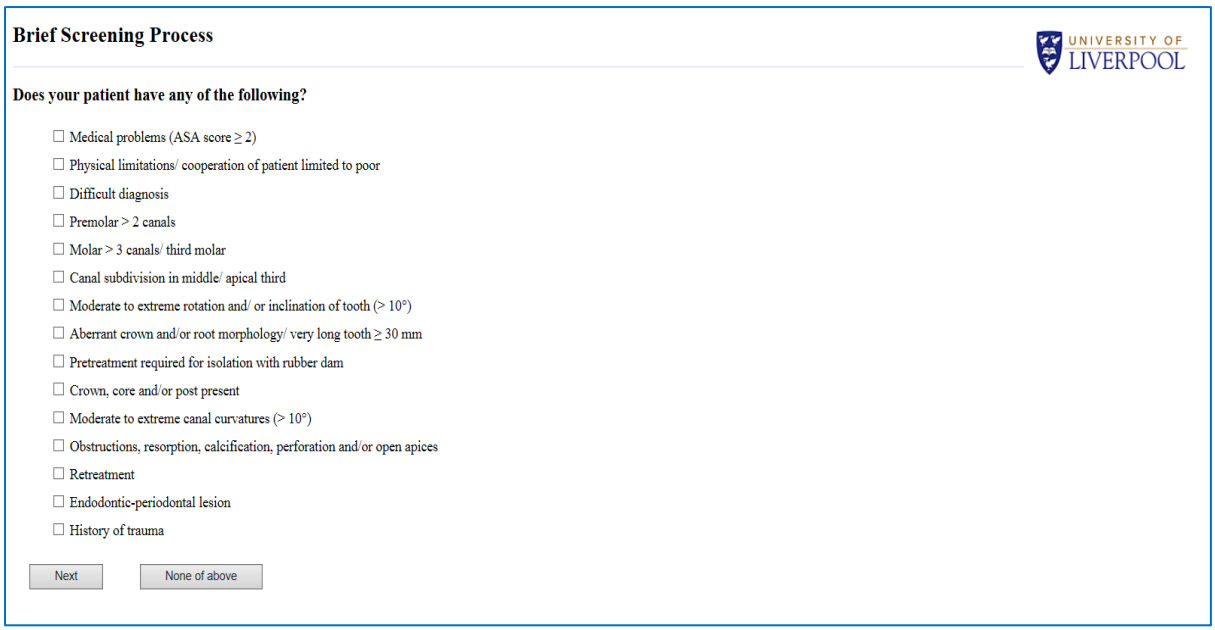

Figure 3-1 showing introduction page as developed for the E-CAT version 1.0. This included a series of 15 questions to tick. If none of those are selected at all, the case is automatically considered uncomplicated.

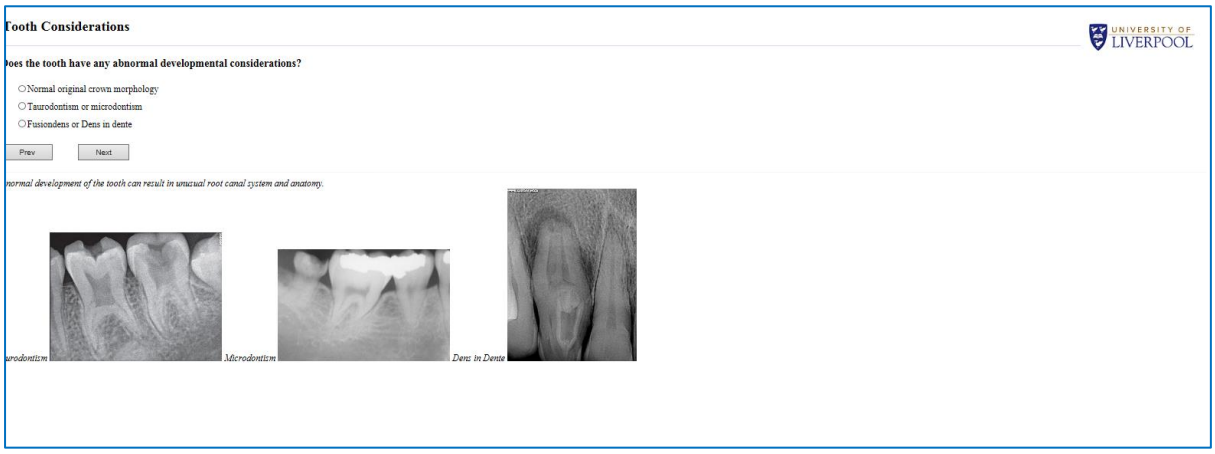

Figure 3-2 showing individual question page as developed for the E-CAT version 1.0. Each page contained the question alongside demonstrations of the question criteria

Report

UNIVERSITY OF LIVERPOOL

Based on the information you have provided, the difficulty of this endodontic treatment is expected to be of :

Class III

15-19 units: Class I 20-25 units: Class II >25 units: Class III

I. Tooth Considerations		
1. What is the position of the tooth in the arch?	1st or 2nd molar	2
2. What is the inclination of the tooth?	No/small inclination (<10°)	1
3. What is the rotation of the toot?		2
4. Does the tooth have any abnormal developmental considerations?	Normal original crown morphology	1
5. Does the tooth need pre-treatment to be isolated?	Simple pre-treatment required for isolation	2
6. What is the access to the root canal system status?	Normal access	1
7. Has the tooth been treated or modified previously?	Metal ceramic crown, metal or ceramic crown	5
8. What is the estimate angle of curvature of the root?		2
9. What is the form or shape of the canal curvature?	Canal curvature into I form	1
10. How many canals are there radiographically or clinically within the root?	Anterior or premolar with 2 canals	2
11. Other treatments or uncommon root morphology	Previously initiated but not completed endodontic treatment	2
12. What is status of the formation of tooth?	Closed (=mature) apex	1
13. Is there any canal calcification evident radiographically or clinically?	Pulp chamber/canals are visible but quite reduced	2
14. Does the root have any signs of resorption? (Multiple choice)	No	0
15. Does the tooth have any of the following iatrogenic complications? (Multiple choice)	No	0
II. Patient Considerations		
1. Does the patient have any medical related problems?	No medical problem (ASA class I)	1
2. What is the mouth opening and endodontic tolerance level? (Multiple choice)	Reduced mouth opening (25-35mm)	2

Figure 3-3 showing the summary page in E-CAT version 1.0, all questions were required to be answered and all information was shown in the summary page.

This version was piloted with 5 dentists to assess 5 cases each. The aim was to evaluate the time it takes for the dentist to assess the cases and gather open feedback from each participant. The results of the pilot study are reported in table 3-1.

Case number	Average time taken (Minutes)	Case type
1	03:57	Uncomplicated UR1 RCT
2	04:24	Uncomplicated LR6 RCT
3	04:05	Uncomplicated UR2 ReRCT
4	04:45	Complicated UR6 RCT
5	05:11	Complicated UR4 ReRCT
Mean	**04:31 (±34s)**	

Table 3-1 showing the pilot study results utilising E-CAT version 1.0. The overall average time require for each case was 4:31 minutes.

The compiled feedback from participating dentists is summarised in table 3-2 below

Complied feedback
Commendation
○ Automatically adds points to arrive assessment (5)
○ Allowed reproducible frame-work (3)
○ Illustration help grasping the subject (2)
○ Good to have summary page (2)
○ Would use again but requires improvement (3)
Criticism
○ Poor user-interface (5)
○ Too lengthy, takes too long (5)
○ Several irrelevant questions (4)
○ Would not use again, prefer using paper format! (2)

Table 3-2 showing the compiled feedback from the dentists using E-CAT version 1.0, all participants commented positively on the concept, but reported negatively on the length and the user interface.

The pilot study and (E-CAT version 1.0) demonstrated a proof of concept that simply converting the existing forms (e.g. AAE or ETC Dutch system) onto an online or digital tool without further modification does not provide a practical solution to the time-consumption issue. The existing paper forms aim to be comprehensive through including criteria and questions to address previous root canal treatment, trauma, patient factors etc. These may not be relevant to cases which do not have those complications e.g. primary endodontic treatment. Reading, answering and adding up those values can add unnecessary time to the process.

The new E-CAT version 2.0 was subsequently developed with the help of two qualified computer programmers. This version contained novel approach to the filtering and surveying questions as deduced from the literature review done in this research, and was not a direct adaptation of the AAE

or the Dutch existing tools as it was in version 1.0. The feedback obtained from the pilot study was taken into account to produce an even more user friendly and less time consuming tool. The language used was PHP MySQL. The idea is for the tool to be available for use across most platforms through a web-based page. Clinicians should be able to access this from desktop computers, laptops or other portable mobile devices.

The tool can be accessed through the following web address:

www.e-cat.uk

A smart filtering mechanism was proposed in order to filter out any irrelevant questions to the case being assessed. The concept was set to have a first page which has a set of surveying questions to help filtering the relevant questions to be asked. This approach is similar to the DETI simple system of determining whether the use of the Endodontic Treatment Classification (ETC) is required (Ree *et al.*, 2003a). Each option selected will only trigger the relevant questions to ask in order to streamline the process and save time on irrelevant questions.

For example, if the endodontic case being assessed was a de novo treatment, all the questions related to root canal retreatment or iatrogenic damage would not be relevant. This makes an obvious opportunity to cut down the number of questions and save on the time of reading and answering them. This method of decluttering is an attempt to simplify the tool without compromising on any other endodontic cases where the questions could be relevant.

Iterative development was used again here in order to ensure the correct filtering mechanism is implemented. The filtering questions were tested several times until a perfect model was achieved. Example of filtering charts can be found in the appendix.

This was implemented through a brief screening page placed prior to the complexity assessment details. The default answer to the screening questions was set as “no” so the user does not need to actively interact prior to going to the next page unless modification is required. When the user

selects yes to any of the screening questions, the relevant complexity criteria will be included on their assessment form.

If the user did not answer yes to any of the screening questions, only the universal questions such as tooth position, canal visibility, root curvature and form would get asked universally, rendering the time required for straightforward cases to be very short.

Each option will carry a certain number of points determined through the iterative development process; the software will be programmed to automatically and efficiently add up those points and come up with an answer to the dentist of how difficult the root canal treatment is expected to be. Once all questions are answered, a summary page is displayed at the end, stating the level of complexity of the case and flagging out in red, amber and whites the factors that have led to that classification. The clinician or the user will also be able to generate and print out a summary report of the case which may be used for referral or patient information purposes.

In summary, in order for the tool to maintain a user-friendly and time efficient interface, the tool was designed into three parts. The first part of the tool contained simple “yes or no” screening questions, following which question filtering mechanism took place. The answers to the screening part will determine the questions appearing on the second part; the surveying questions. Once the user completes their answer to the relevant questions, they are taken to a summary page displaying the classification alongside highlighted complexities if present.

Screen shots of the model can be seen in figures 3-4 to 3-7 below.

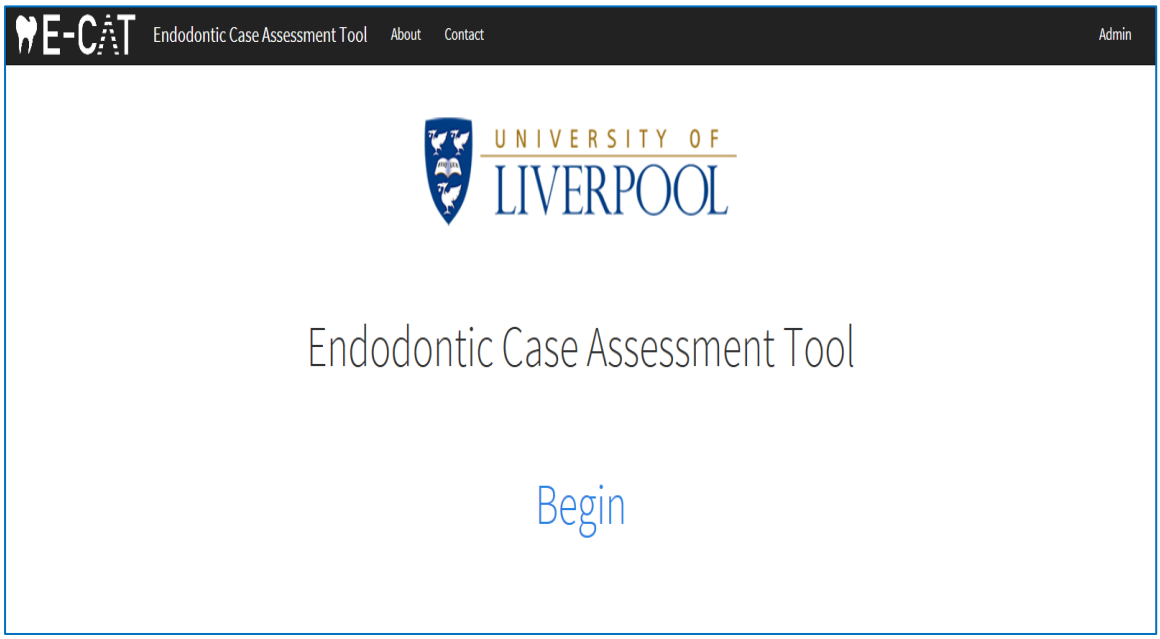

Figure 3-4 showing the simple welcome page of version of E-CAT version 2.0

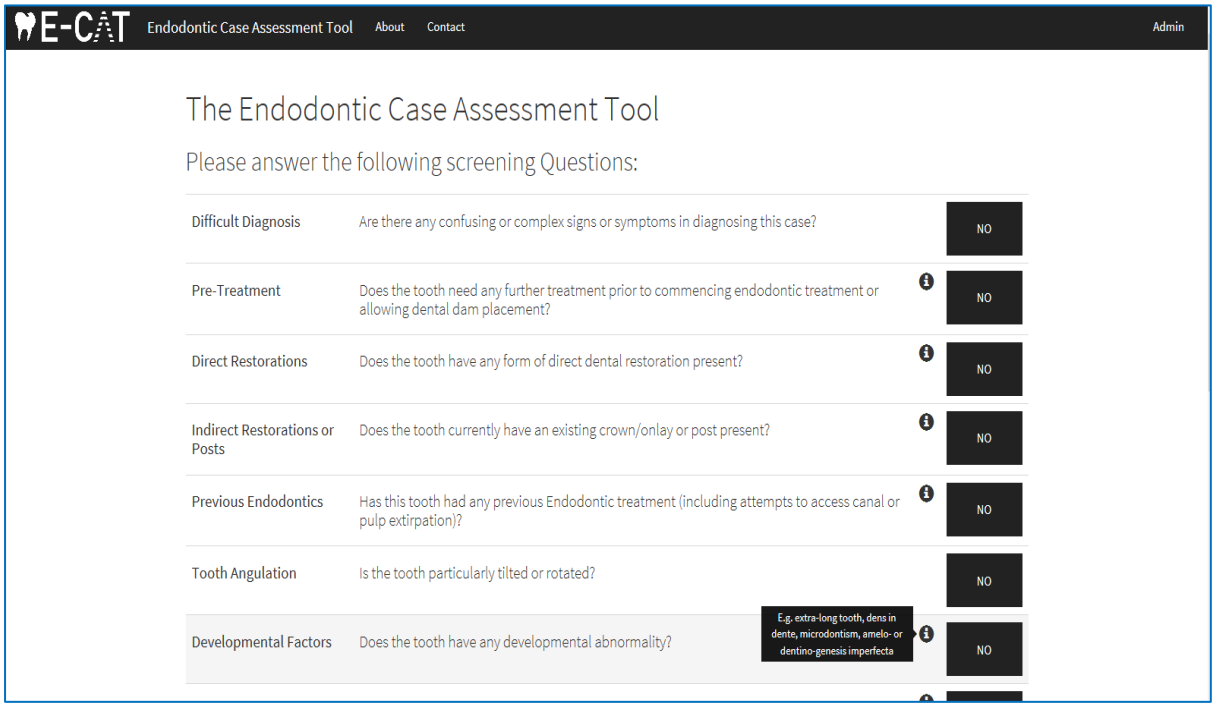

Figure 3-5 showing the screening page of version of E-CAT version 2.0 containing 12 keywords and simple yes or no questions, with the ability to show more information if hovered over the (i) icon.

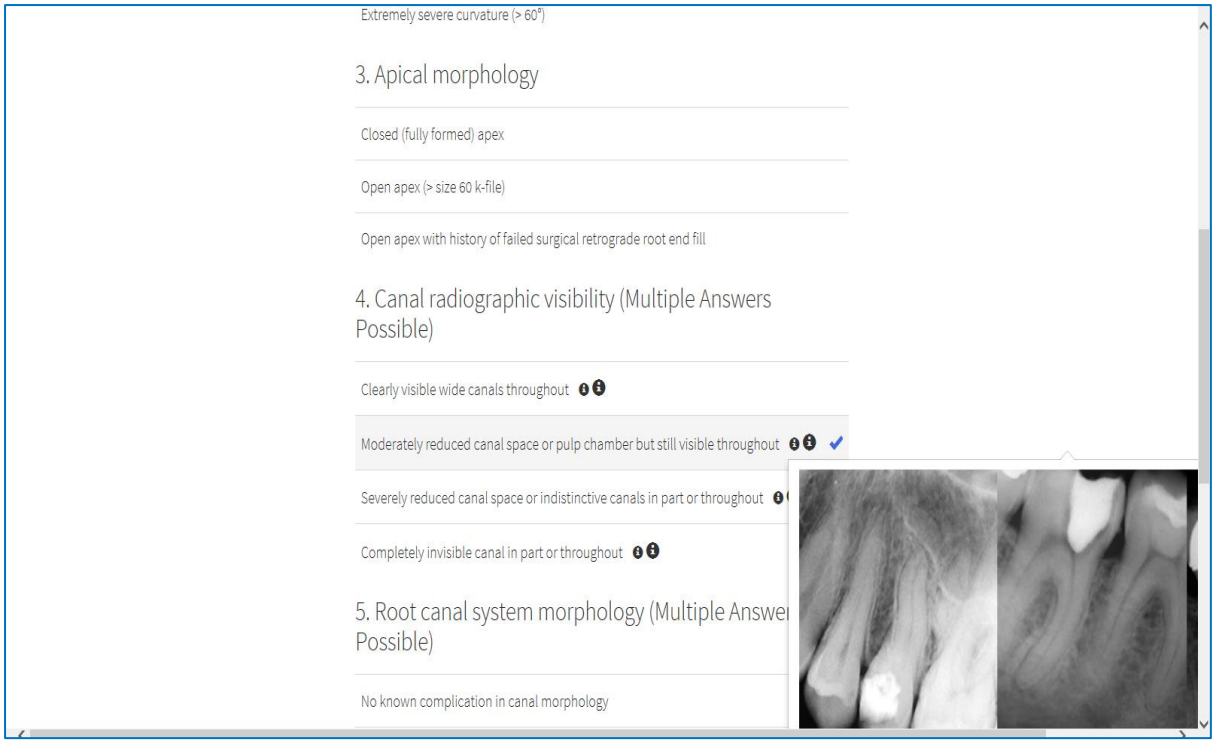

Figure 3-6 showing the surveying page of version of E-CAT version 2.0 only the relevant questions to the case as determined from the filtering page, with the ability to show more information if hovered over the (i) icon.

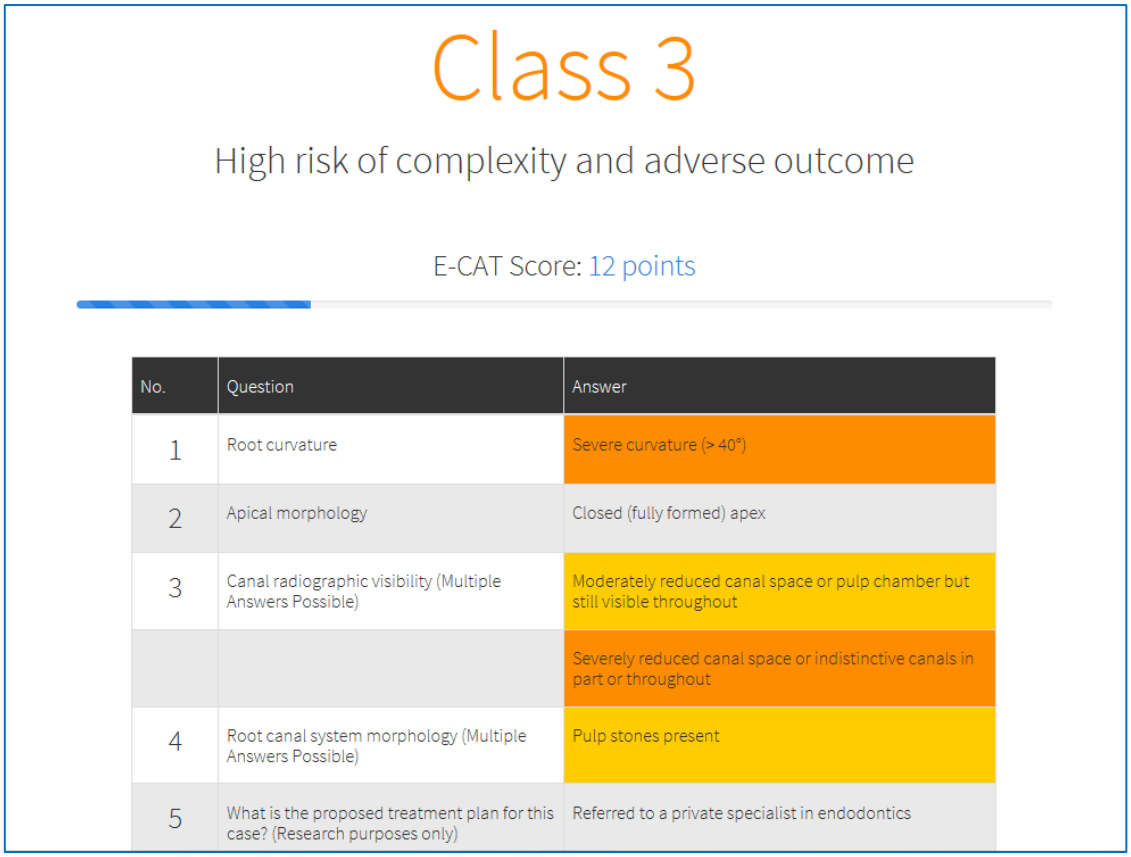

Figure 3-7 showing the summary page of version of E-CAT version 2.0, containing only the relevant information to the case, with colour highlighted risk factors. Factors having moderate risk of complications are highlighted in amber, whilst those posing a higher risk are in dense orange.

3.2.4 Validity study

A panel of three endodontic experts (GDC registered Specialists in Endodontics) was assembled. The panel was provided with 15 anonymised clinical cases with radiographs and pre-treatment clinical information providing the details required to make a pre-treatment judgment on the complexity of the case. Members of the panel were sat together and asked to agree on the complexity of each case with a numerical score of 1, 2 or 3 according to its complexity. The levels were defined as their own judgment of uncomplicated, moderately complicated, and highly complicated respectively. Where members of the panel disagreed on its complexity level, a discussion between them was held until a consensus was achieved.

Those same 15 cases were then analysed using E-CAT version 2.0 with independent inputting (independent calibrated Speciality Registrar in Endodontics) of the clinical information provided into the tool. The results of the panel consensus (class 1, 2 or 3) and the E-CAT classification outcome (1,2 or 3) were recorded on Microsoft Excel spreadsheet (MS Excel 2016, Version 14.0) assessed and the inter-rater *kappa* utilising Statistical Package for Social Sciences (SPSS) software (version 25, SPSS, Inc., Chicago, IL, USA) correlation results were recorded as shown in the results section.

3.2.5 Reliability

A study was designed to assess the inter-rater and intra-rater reliability of the tool. A total of 15 general dental practitioners were recruited through an advert at the University of Liverpool. They were provided with a short tutorial of how to use the tool and allowed the opportunity of assessing 3 independent cases prior to starting the study. Each participant was provided with 15 anonymised clinical cases with radiographs and pre-treatment details required to make a pre-treatment judgment on the complexity of the case. They were then asked to use the E-CAT Version 2.0 tool independently through inputting the clinical information provided with each of the 15 clinical scenarios. All participants were provided with digital radiographs on similar computer screens and the same lighting conditions (HP Probook Laptop 13.3 inch screen). The participants were blinded to the outcome of each case.

The following outcomes were observed and recorded on Microsoft Excel spreadsheet (MS Excel 2016, Version 14.0); the E-CAT class (1, 2 or 3), the time taken for the assessment of each case (seconds), E-CAT score (value in points), criteria selected and the participants own judgement of the case complexity (1, 2 or 3). The users were also asked to rate their experience on how they found the use of the tool on a 0-10 Visual Analogue Scale (VAS), where 0 is very simple and 10 is very difficult.

In order to assess the intra-rater reliability of the tool, the exact same study with the same 15 participants and 15 cases was repeated under the same conditions 9 months after the initial study. The data were recorded and analysed in Statistical Package for Social Sciences (SPSS) software (version 25, SPSS, Inc., Chicago, IL, USA) to each rater as shown in the results section.

3.2.6 External Validity

A panel of 35 independent "experts" in the field of endodontics were recruited. All participants had to be GDC registered endodontic specialists and still practicing endodontics on regular basis. Members were recruited through direct invitation to randomly selected 100 GDC registered specialists (email or post) and direct contact at a regional endodontic scientific meeting in the UK. Similar to the internal validation process, each specialist was again provided with anonymised clinical cases with radiographs and pre-treatment clinical details. Members of the panel were asked to independently assess the complexity of each case with a numerical score of 1, 2 or 3 according to its complexity. The levels were defined as the expert's own judgment of uncomplicated, moderately complicated, and highly complicated respectively.

The results for each panel member and each case was collected and recorded individually on Microsoft Excel spreadsheet (MS Excel 2016, Version 14.0). The inter-rater correlation of each case was calculated and the consensus was assessed by calculating the mode and the weighted kappa for each case.

The validity of the tool was then re-assessed by calculating inter-rater agreement utilising SPSS software (version 25, SPSS, Inc., Chicago, IL, USA) between the 35 members' panel consensus and the independent outcome recoded by using the tool to assess the same cases.

3.3 Results

Following a literature review of the existing tools, a decision was made to produce a web-based digital tool with HTML coded application. HTML was found to be the most diverse language which can be used across different platforms (Microsoft OS or Mac OS) and mobile devices (Mac iOS and Android). It is also the programming language familiar to most computer programmers. The web domain of www.e-cat.uk was purchased and dedicated as the web address for the tool.

3.3.1 Complexity Criteria

Following a wide search of the reported endodontic complexities, numerous complexity factors were determined. The following assessment criteria shown in table 3-3 were most commonly reported and were therefore included on the E-CAT assessment form. These were all discussed in details within section 2.1 of the previous chapter.

Results of literature search on endodontic criteria affecting endodontic treatment complexity
1. Complex diagnosis
2. Pre-treatment prior to commencement
3. Radiographic difficulties
4. Medical history, anaesthesia and patient management
5. History of trauma
6. Physical and psychological limitations
7. Mouth opening
8. The position of the tooth
9. Inclination and rotation of tooth
10. Crown morphology and presence of extra-coronal restoration (crown or onlay)
11. Access to root canal system
12. Root curvature
13. Root canal morphology
14. Apical morphology
15. Canal radiographic visibility
16. Previous endodontic treatment
17. Iatrogenic incidents
18. Root resorption
19. Perioendo (Periodontic-Endodontic) lesion involvement

Table 3-3 Results of literature search on endodontic criteria affecting endodontic treatment complexity. A total of 19 categories were identified to be associated with the risk of encountering complexity or adverse outcomes.

The following two criteria were encountered on the search but were not included on the E-CAT form

- Shape form of the canal (e.g. I shape, J shape)
- Presence and size of periapical pathology
- Canal subdivision in middle or apical third

The presence of S-shape canal was incorporated into root formation as universal question. The reasons for not including them will be further discussed in the discussion section later.

Each criterion was further researched and sub-divided into different level of complexities as determined by the relevant literature. A total number of 22 surveying questions were decided.

These are presented in the table 3-4 below.

Surveying questions for endodontic complexity assessment of non-surgical root canal treatment

1. What is the position of the tooth?

- **Anterior or Premolar**
- **1st or 2nd Molar**
- **3rd Molar**

2. Root curvature

- **Small or no curvature (< 15°)**
- **Moderate curvature (15 - 40°)**
- **Severe curvature (> 40°)**
- **Extremely severe curvature (> 60°)**

3. Apical morphology

- **Closed (fully formed) apex**
- **Open apex (> size 60 k-file)**
- **Open apex with history of failed surgical retrograde root end fill**

4. Canal radiographic visibility (Multiple Answers Possible)

- **Large pulp chamber and clearly visible canals to apex**
- **Reduced pulp chamber volume , narrow yet visible canal space to apex**
- **Indistinct pulp chamber or canal space in part or throughout**
- **Completely invisible canal in part or throughout**

5. Root canal system morphology (Multiple Answers Possible)

- **No known complication in canal morphology**
- **Pulp stones present**
- **S shape canal**
- **C shape or ribbon shape root canal system (this can only be assessed clinically or with CBCT)**

6. Inclination of tooth (degree of tooth tilt)

- **No/small inclination (< 10°)**
- **Moderate inclination (10 - 40°)**
- **Extreme inclination (> 40°)**

7. Rotation of tooth

- **No/mild rotation (< 10°)**
- **Moderate rotation (10 - 40°)**
- **Extreme rotation (> 40°)**

8. Crown Morphology

- **No known developmental abnormality**
- **Taurodontism or microdontism**
- **Dens invaginatus or Fusion**
- **Dentinogenesis imperfecta**

9. Pre-treatment prior to commencement

- No pre-treatment required for isolation
- Simple pre-treatment required for isolation (e.g. supra-gingival caries)
- Extensive pre-treatment required for isolation (e.g. sub-gingival caries, margin elevation)
- Removal of crown or bridge prior to treatment

10. Access to root canal system

- Direct (plastic) restoration but clear crown morphology
- Direct (plastic) restoration masking crown morphology
- Amalgam build up in pulp chamber without post or crown
- Composite core build-up in pulp chamber without post or crown

11. Root Canal Morphology

- Anterior tooth or premolar with one canal
- Anterior tooth or lower premolar with 2 canals
- Premolar with 3 canals
- Very long tooth (> 30mm)
- Molar with ≤ 3 canals
- Molar with ≥ 4 canals

12. Previous endodontic treatment

- Previously initiated but not obturated, endodontic treatment
- Canal(s) obturated with gutta-percha
- Canal (s) obturated with gutta-percha with >2mm overfill
- Canal(s) obturated with other materials (e.g. Silver cones, resin based filling, bioceramic material)

13. Root resorption

- Apical root resorption
- Internal root resorption
- External root resorption

14. Iatrogenic incidents (Multiple Answers Possible)

- No known incident
- Supra-osseous perforations
- Sub-osseous perforations
- Broken instrument
- Ledging
- Apical transportation
- Significantly misaligned previous endodontic access

15. Medical history, anaesthesia and patient management (Multiple Answers Possible)

- No medical problem or well controlled MH - ASA Class II
- Diabetes (poorly controlled)
- Vasoconstrictor intolerance
- Complex MH ASA III or VI including Haemophilia
- IV bisphosphonate or had history of head and neck radiotherapy
- Allergy to anaesthesia

16. Mouth opening

- Normal mouth opening (>35mm)
- Reduced mouth opening (25-35mm)
- Extremely reduced mouth opening (<25mm)

17. Physical and Psychological limitations (Multiple Answers Possible)

- None
- Lack of cooperation/ nervous patient
- Extremely nervous – needs sedation
- Moderate Limited reclination
- Unable to recline

18. Radiographic difficulties (Multiple Answers Possible)

- Normal conditions
- Severe gag reflex
- Narrow or low palatal vault/High floor of mouth
- Hard to solve superimposed anatomical structures

19. Diagnosis

- Uncomplicated clear diagnosis
- Differential diagnosis of usual signs and symptoms possible, but adjacent teeth could be involved
- Confusing and complex signs of symptoms: difficult or unable to achieve clear diagnosis

20. History of trauma (Multiple Answers Possible)

- Unknown type of trauma in the past
- Uncomplicated crown fracture
- Root fracture in apical third
- Concussion
- Complicated crown root fracture of mature teeth
- Root fracture in middle third
- Subluxation /alveolar fracture
- Complicated crown root fracture of immature teeth
- Root fracture in cervical third
- Other luxations/avulsions

21. Is there any Perioendo (Periodontic-Endodontic) lesion involvement (Multiple Answers Possible)

- **Furcation involvement**
- **Perio-endo lesion**
- **Mobility, fenestrations or dehiscence**
- **Root resection or hemi-section expected or completed**

22. Extra-coronal restoration

- **Crown, bridge or onlay present but planned to be removed prior to commencing treatment**
- **Core build-up in pulp chamber**
- **Access required through crown or onlay**
- **Poorly adapted post**
- **Well adapted and firmly cemented post or cast post and core**

Table 3-4 showing the complexity factors reported to be linked to the complexity of non-surgical root canal therapy

3.3.2 Iterative development

A total of 32 iterative cycles were conducted prior to achieving a perfectly fitting model for the 75 clinical cases as described in the methods section. The iterative cycles did not change the questions being asked but rather the value and impact of each of those factors.

Following the first few cycles, it immediately became evident a wider range of values was required. The range was changed to 0-10 E-CAT points for each factor depending on its complexity (E-CAT version 2.1). The range of values for classification outcome also needed to change. The E-CAT total score range for cases was changed to start from 0 for ultimate very low risk of complication case, and as high up as 50 for the ultimate realistically encountered complex endodontic treatment. The true maximum E-CAT score if all the complexities were to combine and occur in one case is 185 points. However, such a case is highly unrealistic or practically impossible to encounter.

Table 3-5 below shows the model of classification which is a perfect fit to the iterative development.

Class	score	Terminology and significance
1	0-5	Uncomplicated; low risk of complexity and adverse outcomes
2	6-11	Moderately complicated; moderate risk of complexity and adverse outcomes
3	>11	Highly complicated; high risk of complexity and adverse outcomes

Table 3-5 showing the range of E-CAT score to describe the class of each case. An E-CAT score up to 5 was found to be of relatively low risk of encountering complexity and is thought to be associated with relatively uncomplicated cases. A score of 12 or above is found to have a high risk of complication and adverse outcome

Tables 3-6, 3-7 and 3-8 on the following 3 pages show the model of E-CAT score weighting for each criterion and complexity factor which is a perfect fit to the iterative development stage.

Question	Surveying questions for endodontic complexity assessment of non-surgical root canal treatment	E-CAT points
1	Diagnosis	
	• Uncomplicated clear diagnosis	0
	• Other adjacent teeth could be involved. Requires simple further investigation.	1
	• Confusing and complex signs of symptoms: difficult or unable to achieve clear diagnosis	10
2	Medical history, anaesthesia and patient management (Multiple Answers Possible)	
	• No medical problem or well controlled MH - ASA Class II	0
	• Uncontrolled diabetes	1
	• Vasoconstrictor intolerance	2
	• Complex MH ASA III or VI including Haemophilia	10
	• Patient is on IV bisphosphonate or had history of head and neck radiotherapy	6
	• Allergy to anaesthesia	10
3	Pre-treatment prior to commencement	
	• Simple or no pre-treatment required for isolation (e.g. supra-gingival caries)	0
	• Extensive pre-treatment required for isolation (e.g. sub-gingival caries, margin elevation)	3
	• Surgical crown lengthening or orthodontic extrusion (existing margins are crestal level)	10
	• Removal of crown or bridge prior to treatment	0
4	Access to root canal system	
	• Average size restoration. Routine access.	0
	• Large plastic restoration masking crown morphology	1
	• Amalgam build up in pulp chamber without post or crown	1
	• Composite build up in pulp chamber – no crown placed	2
5	Extra-coronal restoration	
	• Crown, bridge or onlay present but planned to be removed prior to commencing treatment	2
	• Composite core build-up in pulp chamber	2
	• Access required through crown or onlay	4
	• Poorly adapted post	4
	• Well adapted and firmly cemented post/cast post and core	8
6	Previous endodontic treatment	
	• Previously initiated but not obturated, endodontic treatment	2
	• Canal(s) sub-optimally obturated with gutta-percha	4
	• Canal (s) well-obturated with gutta-percha or obturation is >2mm overfilled	9
	• Canal(s) obturated with other materials (e.g. Silver cones, resin based filling, bioceramic material)	10
7	Iatrogenic incidents (Multiple Answers Possible)	
	• No known incident	0
	• Supra-osseous perforations	4
	• Sub-osseous perforations	10
	• Coronally separated instrument or clinically visible	6
	• Apically separated instrument or clinically not visible	10
	• Overt ledge or apical transportation	10
	• Significantly misaligned previous endodontic access	3
8	Inclination of tooth (degree of tooth tilt)	
	• No/small inclination (< 10°)	0
	• Moderate inclination (10 - 40°)	1
	• Extreme inclination (> 40°)	4

Table 3-6 showing breakdown of the E-CAT score associated with the risk of encountering complexity or adverse outcomes. A score of zero represents low or no relative risk, 10 represents very high risk.

Question	Surveying questions for endodontic complexity assessment of non-surgical root canal treatment	E-CAT points
9	. Rotation of tooth	
	• No/mild rotation (< 10°)	0
	• Moderate rotation (10 - 40°)	1
	• Extreme rotation (> 40°)	4
10	Crown Morphology	
	• No known developmental abnormality	0
	• Taurodontism or microdontism	2
	• Fusion or dens invaginatus	10
	• Dentinogenesis imperfecta	10
11	Root Canal Morphology	
	• Anterior tooth or premolar with one canal	0
	• Anterior tooth or lower premolar with 2 canals	6
	• Premolar with 3 canals	8
	• Very long tooth (estimated working length> 30mm)	5
	• Molar with ≤ 3 canals	0
	• Molar with ≥ 4 canals	4
12	. Root resorption	
	• Apical root resorption	2
	• Internal root resorption	10
	• External root resorption	10
13	Is there any Perioendo (Periodontic-Endodontic) lesion involvement (Multiple Answers Possible)	
	• Furcation involvement	1
	• Perio-endo lesion	5
	• Mobility/fenestrations/dehiscence	2
	• Root resection/hemi-section expected or completed	10
14	Dental trauma (Multiple Answers Possible)	
	• Unknown type of trauma in the past	2
	• Uncomplicated crown fracture	1
	• Root fracture in apical, mid root or cervical	10
	• Concussion or Subluxation	2
	• Complicated crown root fracture of mature teeth	5
	• Complicated crown root fracture of immature teeth	10
	• Other luxations/avulsions	10
		10
15	Mouth opening	
	• Normal mouth opening (>35mm)	0
	• Reduced mouth opening (25-35mm)	2
	• Extremely reduced mouth opening (<25mm)	6
16	Physical and Psychological limitations (Multiple Answers Possible)	
	• None	0
	• Lack of cooperation or significantly nervous patient	2
	• Patient requires sedation	6
	• Moderate limited reclination	1
	• Unable to recline	6
17	Radiographic difficulties (Multiple Answers Possible)	
	• Normal conditions	0
	• Severe gag reflex	4
	• Narrow or low palatal vault/High floor of mouth	1
	• Hard to solve superimposed anatomical structures	6

Table 3-7 showing breakdown of the E-CAT score associated with the risk of encountering complexity or adverse outcomes. 0 represents low or no relative risk, 10 represents very high risk.

Question	Surveying questions for endodontic complexity assessment of non-surgical root canal treatment	E-CAT points
18	What is the position of the tooth?	
	• Anterior or Premolar	0
	• 1st or 2nd Molar	2
	• 3rd Molar	6
19	Root curvature	
	• Small or no curvature (< 15°)	0
	• Moderate curvature (15 - 40°)	1
	• Severe curvature (> 40°)	4
	• Extremely severe curvature (> 60°)	9
20	Apical morphology	
	• Closed (fully formed) apex	0
	• Open apex (> size 60 k-file)	8
	• Open apex with history of failed surgical retrograde root end fill	10
21	Canal radiographic visibility (Multiple Answers Possible)	
	• Clearly visible canals throughout	0
	• Moderately reduced pulp chamber or canal space but still visible throughout	1
	• Severely reduced or indistinctive canal space or pulp chamber in part or throughout	6
	• Completely invisible canal in part or throughout	10
22	Root canal shape and pulp stones (Multiple Answers Possible)	
	• No known complication	0
	• Pulp stones present	2
	• S shape canal	6
	• C shape or ribbon shape root canal system (this can only be assessed clinically or with CBCT)	7

Table 3-8 showing breakdown of the E-CAT score associated with the risk of encountering complexity or adverse outcomes. 0 represents low or no relative risk, 10 represents very high risk.

As previously anticipated, it can be seen from the tables that the level of details required for a comprehensive complexity assessment form would result in a lengthy, time consuming and mathematically demanding form. Iterative development cycles were used to develop the screening questions. A total of 17 iterative cycles were required to develop a perfect fit model. Fourteen questions were selected to be included on the screening section.

	Screening criterion	Question	Linked questions
1	Complex Diagnosis	Are there any confusing or complex signs or symptoms in diagnosing this case?	1
2	Medical History	Are there any medical history factors related to this treatment?	2
3	Pre-Treatment	Does the tooth need any further treatment prior to commencing endodontic treatment or allowing dental dam placement?	3
4	Direct Restorations	Does the tooth have any form of direct dental restoration present?	4
5	Indirect Restorations or Posts	Does the tooth currently have an existing crown/onlay or post present?	5
6	Previous Endodontics	Has this tooth had any previous Endodontic treatment (including attempts to access canal or pulp extirpation)?	6,7
7	Tooth angulation	Is the tooth particularly tilted or rotated?	8,9
8	Development factors	Does the tooth have any developmental abnormality?	10
9	Complex morphology	Is it known if the tooth has increased number of canals or root length?	11
10	Root resorption	Does the tooth have any signs of root resorption?	12
11	Periodontics	Are there any localised deep periodontal involvement?	13
12	Trauma	Has the tooth had known history of dental trauma?	14
13	Patient factors	Are there any patient related factors that could interfere with this treatment?	15,16
14	Radiographs	Are there any restrictions to taking or interpreting radiographs?	17

Table 3-9 showing the main key areas dictating the factors which could impose higher risk of encountering complexity and the questioning required to be assessed should one those areas be involved in the case. For example, if the tooth being assessed has only had previous endodontics and direct restorations, then only questions 4, 6 and 7 will be shown on the surveying forms, in addition to the default questions of 18 to 22.

Question 18,19,20,21 and 22 of the surveying questions were found to be universal and can be linked to any endodontic treatment regardless of the clinical history, they were therefore not linked to any screening questions. If the user was not to select any “yes” answers from the screening page, only those 5 would automatically show on the surveying page.

3.3.3 Pilot Validation

The panel of three endodontic specialists assessed 15 digitally randomised cases independently. The results of each panel member were recorded. Cases are attached in appendix 7.7. The panel disagreed on a total of 3 cases out of the 15. A consensus was agreed following discussion on reasoning. The cases were then assessed independently by the author using the latest E-CAT version following the iterative development process. The results of this study are shown in table 3-10.

Case number	Observer 1	Observer 2	Observer 3	Consensus	E-CAT outcome	Consensus in agreement with E-CAT
1	1	1	1	1	1	Yes
2	3	2	2	2	2	Yes
3	3	3	3	3	3	Yes
4	3	3	3	3	3	Yes
5	1	1	1	1	1	Yes
6	2	2	2	2	2	Yes
7	2	2	2	2	2	Yes
8	2	2	2	2	2	Yes
9	3	3	3	3	3	Yes
10	3	3	3	3	3	Yes
11	1	1	1	1	1	Yes
12	3	3	3	3	3	Yes
13	3	3	3	3	3	Yes
14	3	3	3	3	3	Yes
15	2	2	2	2	2	Yes

Table 3-10 showing the results of the pilot validation which involved a panel of three endodontists assessing 15 clinical cases, and the results of the panel compared to the results reported by E-CAT.

The radiographs of the three cases the panel disagreed on and achieved consensus, are in the table below.

Case	Discussion
	One member of the panel felt the presence of the crown and failed endodontic treatment would significantly complicate case and rated it 3. However, following discussion the member agreed due to the presence of suboptimal obturation and if the crown was to be removed or with the use of portable magnification, this case complexity would not be “high”. The member agreed to rate this as 2.
	One member of the panel felt the severe misalignment of the endodontic access in the LR3 and the severity of canal reduction would class this case as 3. Following discussion to state there is no perforation, tooth is anterior and canal is radiographically still visible, the rating was lowered to 2.
	One member of the panel felt the position of the tooth being second molar (LR7) and moderately reduced mouth opening would push this to class 3. The panel commented on the mouth opening not being “severely” reduced but “moderately” reduced, and no other significant complications being present. The rating was agreed to be 2.

3.3.4 Reliability

A total of 15 dentists were recruited to assess the reliability of the E-CAT. The mean age for the dentists was 29.7 years, and mean number of years post qualification being 5.6 years. There were 9 male dentists and 6 female dentists. At the time of their inclusion, those were dentists with no further formal qualifications in endodontics. The same 15 dentists repeated the same study 9 months later. The results of the first study are shown in table 3-13. The inter-rater kappa was calculated to be (k= 0.75) for the first experiment.

Case number	Dentists achieving outcome of Class 1	Dentists achieving outcome of Class 2	Dentists achieving outcome of Class 3	Average Time taken for assessment	E-CAT outcome	Agreement
1	15	0	0	01:08	1	100%
2	2	13	0	01:28	2	86%
3	0	15	0	01:15	3	100%
4	0	2	13	01:57	3	86%
5	15	0	0	00:32	1	100%
6	0	13	2	02:33	2	86%
7	0	13	2	01:23	2	86%
8	2	13	0	01:20	2	86%
9	0	1	14	01:45	3	93%
10	0	3	12	01:13	3	80%
11	15	0	0	02:05	1	100%
12	0	1	14	02:10	3	93%
13	0	1	14	02:16	3	93%
14	0	0	15	01:38	3	100%
15	0	13	2	01:36	2	83%
Mean				01:37	SD±31s	91%

Table 3-11 Primary data of reliability study showing the results of 15 dentists using the E-CAT to assess 15 clinical cases. The overall kappa for the first study was 0.75. The mean time taken to assess the cases was 97s with (SD±31s)

The results of the repeated study are shown in table 3-12. The inter-rater kappa was calculated to be (k= 0.80) for the second experiment.

Case number	Dentists achieving outcome of Class 1	Dentists achieving outcome of Class 2	Dentists achieving outcome of Class 3	Average Time taken for assessment	E-CAT outcome	Interclass Coefficient agreement
1	15	0	0	01:35	1	100%
2	0	14	1	01:55	2	93%
3	0	15	0	01:22	3	100%
4	0	2	13	01:55	3	86%
5	15	0	0	00:31	1	100%
6	0	13	2	02:25	2	86%
7	0	14	1	01:45	2	93%
8	2	13	0	01:37	2	86%
9	0	1	14	01:40	3	93%
10	0	2	13	00:32	3	86%
11	15	0	0	01:27	1	100%
12	0	1	14	00:55	3	93%
13	0	1	14	01:35	3	93%
14	0	0	15	01:30	3	100%
15	0	13	2	01:18	2	86%
Average				01:29	SD±32s	93%

Table 3-12 Repeated study data of reliability study 9 months later showing improved results of 15 dentists using the E-CAT to assess the same 15 clinical cases. The overall kappa for this study was 0.8. The mean time taken to assess the cases was 89s with (SD±32s)

As can be seen, the participants failed to achieve perfect agreement on few cases. A summary of the reasons are explained below.

Case	Reasons
	Variation due to selection of "optimal obturation" for this case. Selection of apical resorption or forgetting to add indirect restoration.
	Aside from open apex and previous endodontic treatment, some dentist did not select history of trauma, child cooperation level and reduced mouth opening as related factors to assess here.
	Some dentists selected "severely" reduced canal space here as opposed to the majority selecting moderately reduced. Selection of C-shape instead of S-shape.

	One dentist selected completely invisible canal space where another selected clearly visible canal space. Another dentist selected perforation as iatrogenic damage. One dentist did not select significantly misaligned access.
	Variation in not selecting history of previous endodontic access, not assessing degree of tilt or choosing severely reduced or indistinct canal space over moderate reduction here.

Table 3-13 showing the cases which showed disagreement between the dentists and the reasons for the disagreement

The dentists were also asked to rate their experience of ease of use of the tool on a scale of 0 (very simple) to 10 (very difficult). The results for the intra-rater reliability and participant's perception of ease of use were as shown in table 3-14.

Dentists	Intra-rater reliability Weighted kappa (CI 95%)	Ease of use rating (0 –simple, 10 difficult)
1	0.91 (0.75 -1)	1
2	0.91 (0.75 -1)	1
3	0.83 (0.61 -1)	2
4	0.73 (0.47 -1)	3
5	1	1
6	1	0
7	0.91 (0.75 -1)	4
8	0.91 (0.75 -1)	3
9	1	2
10	0.83 (0.61 -1)	2
11	1	1
12	0.83	3
13	0.91 (0.75 -1)	2
14	1	1
15	0.83 (0.61 -1)	4
Mean	0.90 (0.74-1)	2

Table 3-14 showing the inter-rater reliability of the 15 dentists taking part in this study, the overall mean kappa was found to be (k= 0.90)

Further analysis of the reliability study results shows that participants seem to have good intra-rater reproducibility when repeating the assessment. However, the most common reasons for not achieving higher inter-rater reliability were the subjectivity of some of the complexity factors when assessed by the observer. The most common reasons for inter-variation across the participants are listed in the table below.

Most common factors resulting in inter-rater variability	Frequency of error % (n= 450 assessments)
Canal visibility	16%
Root curvature	11%
Degree of inclination of tooth	3%
Not stating	
• **History of trauma**	3%
• **Previous endodontic treatment**	3%
• **Iatrogenic damage**	2%
• **Reduction in mouth opening**	1%
• **Medical history**	1%
Overstating apical root resorption	1%
Accidently stating unrelated factors	3%
Other miscellaneous errors	3%

Table 3-15: the most common variations and errors encountered by the dentists while utilising the E-CAT. Assessing canal visibility and root curvature were found to be the most prevalant variation between the group despite the lack of confounding factors.

3.3.5 External Validity

Utilising the GDC specialist list register, a total of 100 email and post invitations were sent. A total 35 GDC registered endodontic specialists volunteered and were recruited to be on the panel giving an initial response rate of 35%. All participants received a participant information letter and 15 cases as attached in the appendix. All volunteers completed the assessment successfully. The results of this validation process are shown in table 3-15 below.

Case number	Experts rating Class 1	Experts rating Class 2	Experts rating Class 3	Agreement	Overall Panel Consensus	E-CAT independent valuation	Consensus in agreement with E-CAT
1	29	5	1	82%	1	1	Yes
2	6	24	5	68%	2	2	Yes
3	0	0	35	100%	3	3	Yes
4	0	6	29	82%	3	3	Yes
5	28	6	1	80%	1	1	Yes
6	1	21	13	60%	2	2	Yes
7	1	18	16	51%	2	2	Yes
8	6	22	7	62%	2	2	Yes
9	0	2	33	94%	3	3	Yes
10	0	1	34	97%	3	3	Yes
11	23	9	3	65%	1	1	Yes
12	0	2	33	94%	3	3	Yes
13	1	6	28	80%	3	3	Yes
14	1	2	32	91%	3	3	Yes
15	3	25	7	71%	2	2	Yes

Table 3-16 showing the results of the external validation study utilising a panel of 35 endodontists independently assessing the same clinical 15 scenarios for their complexity. Rating them 1 (uncomplicated), 2 (moderately complicated) and 3 (highly complicated). The overall panel consensus agreed with the outcome of the E-CAT in all 15 cases.

The overall average of panel agreement was 78%. The inter-rater reliability was found to be moderate (Kappa = 0.51, 95% CI: 0.49 to 0.52).

3.4 Discussion

The study design and methodology overall succeeded in meeting the aims and objectives set in the introduction of this research. Producing a comprehensive list of the factors associated with endodontic treatment complexity was found to be a challenging process. Despite the Canadian, AAE, EDTI, ETC and the RIOTN forms all reporting similar criteria, little high-quality evidence was found to support them. The criteria included for this research were selected following an in-depth review of the literature. Evidence selected ranged from case reports, narrative reviews, expert opinions up to the utilisation of systematic reviews reporting on prognostic factors affecting the success and survival of endodontic outcomes.

The 19 criteria listed in the results and the 22 questions designed to address them appeared to be fairly comprehensive and address all possible factors which may affect endodontic complexity. The iterative development process did not reveal missing factors, and the feedback received from the dentists and specialists who took part in the study commented on the comprehensiveness of the questions with no suggestions being made to add further complexity factors.

The participants did however comment on possible superfluous factors which were initially included in E-CAT version 1.0 and were rather confusing to the users. The main criteria that were subsequently omitted were the form or shape of the root and the presence of large periapical lesion.

Four out of the 5 dentists included in the pilot study commented on the confusion associated with "J-shaped" and "I-shaped" roots. The literature review did not show any evidence to support whether and I shape or J shape roots would affect the complexity of the case. The degree of root curvature usually would account for the present of "J-shaped" rooted. Evidence however was present for the complexity of managing C-shape canals and S-shaped roots (Machado *et al*., 2014a, Sakkir *et al*., 2014, Martins *et al*., 2013). This was included as a universal question. The criterion of C-shape canals however can only realistically be assessed from clinical information or if a CBCT radiograph were available (Fan *et al*., 2004). A decision to omit I and J shape criteria was therefore

made. The S-shape and C-shape criteria were included under complex morphology of the root canal system.

The presence of a periapical lesion and the size of periapical lesions prior to endodontic treatment were well documented as prognostic factors in endodontic outcomes (Ng *et al*., 2008, Marquis *et al*., 2006). Those studies both reported a statistically significantly lower strict criteria success rate (ESE, 2006) when the teeth were associated with the presence of pre-operative periapical lesions. The technical complexity of endodontic treatment itself however, or even the technical quality of the endodontic treatment did not appear to have a statistically significant difference on the overall outcome and tooth survival as opposed to success outcome (Ng *et al*., 2010, Pak *et al*., 2012). It can be concluded from the current literature review that even though the presence of a periapical lesion is a prognostic factor in achieving a successful outcome, it is not reported to complicate the technical aspects of endodontic treatment any further. A decision was therefore made not to include the presence of a periapical lesion as a complexity factor in this tool.

The final omission of complexity made was canal subdivision in the middle or apical third. This was found to be a reported complexity in several publications (Albuquerque *et al*., 2014, Wu *et al*., 2017, Reddy *et al*., 2012). However, those same publications reported on the difficulty of diagnosing those using pre-apical radiographs or other 2-D imaging. The evaluation of the DETI tool (Ree *et al*., 2003a) reported on the vagueness of this criterion as reported by the dentists. Usually this appears as an indistinct area where the canals disappear in the radiograph or as two distinct canals within the root canal system if the radiographic angle was favourable. Both of these factors are accounted for within the "canal visibility" criteria or the "root canal morphology" criteria surveying questions. Incorporating the question into those was thought to be less ambiguous for the less experienced clinicians.

The use of iterative development in the medical field for the development of assessment or scoring tools is not uncommon. A group of orthopaedic surgeons (Haugen *et al*., 2014), published data on

the usefulness of this approach for their development of “OMERACT”, hand osteoarthritis MRI scoring system. They reported “good to very good” inter-rater reliability. Another pharmacological group (Melton *et al*., 2016) used the same approach to develop a clinical decision support system, “CDSS”, for pharmacogenomic-guided warfarin dosing designed for physicians and pharmacists; they reported “good” overall satisfaction and a significant time-saving improvement. In the development of E-CAT, the iterative development process proved time consuming to achieve a perfect fit model. The number of iterations required proved higher than those reported in the above two research studies but this is possibly due to the higher number of factors involved and the high number of calibrating cases selected to ensure a fitting model.

In comparison to the existing endodontic assessment forms (AAE, 2005a, Ree *et al*., 2003a), the score values and the complexity score range for the classes were significantly transformed. Rather than adhering to the 1,2 and 5 points scoring system, the range of values was changed to be anywhere between 0-10, adding 8 further possible scoring points to the range. This was found necessary early on the iterative development process as the arbitrary values of 1, 2 and 5 could not provide a fitting model to the first 8 assessed cases. It is speculated that the existing AAE and other paper forms used those values purely for the ease of use on the paper-format forms in order to help their users to easily sum-up the points without the need for a calculator or lengthy mathematical additions. As this research uses an automatic calculating system, the use of simple values was no longer required, and increasing the score range to increase the accuracy of the assessment was made possible.

As a direct consequence of increasing the choice of possible scores, the range of values associated with the other published assessment tools did not match. Rather than having a range of values starting at 15-19, 20-25 and above 25, for the relevant complexity classes, the range that best fit the iterative development model was changed here to be 0-5, 6-11 and >11.

This change has enabled the tool to add another dimension to complexity assessment. The ability to produce a score value (E-CAT score), makes it possible to add more depth and character to the classes rather than being plain 1, 2 and 3.

It is important to understand however that the E-CAT is not yet designed to form a "linear" relationship with the complexity expected. Further research would be required to validate the exact relationship between the score and the clinical complexity. The E-CAT score is therefore kept hidden at this stage.

The range of endodontic complexity is documented to vastly vary between cases (Caplan *et al*., 1999, Falcon *et al*., 2001, Messer, 1999, Muthukrishnan *et al*., 2007). It was found particularly challenging to agree to group all those in only 3 classes. This can be clearly seen from the results obtained following having the 35 endodontists giving their judgment on a sample of 15 clinical cases.

Some assessment tools argued the usefulness of using scores and numbers all together (AAE, 2005a, Falcon *et al*., 2001) and attempted producing algorithms which uses factors such as x, y or z in combination, independent of any scores. An example of that is the RIOTN or the classic AAE form. An advantage of that was thought to be simplifying the form itself and the difficulty of assigning a realistic value to each factor. However, this study, agrees with the finding of (Muthukrishnan et al., 2007, Ree et al., 2003a) and (Curry, 2010) that completely abandoning a point-scoring system would be too simplistic and will results in less sensitive and reproducible results overall. For example, if a case had moderate root curvature in addition to moderate canal space reduction and moderate tooth tilt and rotation in addition to uncontrolled diabetes and moderate reduction in mouth opening – all these factors carry different weighting, and in isolation may seem to moderately complicate a case, but all together would probably result in higher risk of complexity and adverse outcomes. The simplest way producing an algorithm to assess whether these factors will combine into a high complexity, was to give them a score value which can be added up in the background. To

overcome the issue of assigning a realistic value to each complexity factor, the iterative development process was followed in this research and proved successful.

Strictly speaking however, the clinicians do not need to know these exact values are as long as it is automated in the background. Informing the clinicians the weighting of and value of each factor is likely to complicate the platform and confuse the clinicians.

One of the main aims of this research was to be able to produce a more accurate and detailed definition of the term "uncomplicated" endodontic or non-surgical root canal therapy as described by the ESE and ADEE. Strictly speaking, the literal definition of this term based on the results above is those cases which score 0 utilising the tool. Those are well and truly uncomplicated cases with very low risk adverse outcome. However, it is important to make it clear that the term "uncomplicated" refers to a wider range of cases in educational environments. Generally it used to define those cases which have a low risk of encountering technical difficulty or an adverse outcome.

Based on the results from the literature review, iterative development and the large specialist panel, an E-CAT score of ≤5 (Class 1) would be a reasonable definition of uncomplicated non-surgical root canal treatment. In this research, these are described as "uncomplicated cases, with low risk of adverse treatment outcome". This defines those cases suitable to be carried out by dental student, recent dental graduates or dentists without any further form of post-graduate training in endodontics.

The definition of "uncomplicated" is discussed in more depth in Chapter 5 (5.2).

As for classes 2 (moderately complicated) and 3 (highly complicated), the results obtained from the external validation study clearly showed that the view of grouping the wide range of endodontic complexity into 3 classes is relatively too simplistic. This is discussed in more details later.

In statistical terms, the inter-rater agreement statistic kappa and weighted Kappa as described by (Cohen, 1968) were calculated. Computation details are also given in (Altman, 1991). The standard error and 95% confidence interval were also calculated.

The K value can be interpreted as follows (Altman, 1991).

Value of K	Strength of agreement
< 0.20	Poor
0.21 - 0.40	Fair
0.41 - 0.60	Moderate
0.61 - 0.80	Good
0.81 - 1.00	Very good

Table 3-17 showing K value interpretation as described by Altman in 1991

The inter-user and intra-user reliability in this study was found to be 0.80 and 0.90 respectively, which can both be interpreted as very good reliability results.

The development and validation of E-CAT can be compared against other well-established clinical assessment tools in Dentistry. For instance, the Index of Orthodontic Treatment Need (IOTN) is a widely used tool in the orthodontic community. It became a public health commissioning tool and a contractual requirement in the NHS in England and Wales since the introduction of the most recent dental contract in 2006 (Jawad *et al*., 2015) . The tool was first developed in 1989 following modification of the index used by the Swedish Dental Health Board (Brook and Shaw, 1989). The validation process was sought in several studies. The accuracy or validity of the IOTN index was assessed against the mean opinion of the orthodontic raters (panel of 18 orthodontists) as a "gold standard" (Younis *et al*., 1997) . The overall agreement obtained for IOTN was 83% for inter-examiner for the dental health component.

In comparison, this study had a panel of 35 endodontists. The overall inter-examiner agreement achieved was 78%. Perfect agreement was only achieved in one case (case 3) out of the 15 cases provided. Very good agreement was achieved in 8 cases (1, 3, 4, 5, 9, 12, 13 and 14). Good

agreement was obtained on 4 cases (2, 8, 11 and 15), one moderate agreement with case 7 and one poor agreement with case 6. The possible reasons for the variation in agreement are discussed below.

Case	Discussion
	The only case that achieved 100% agreement from the panel with all members rating it as highly complex or class 3. This case is classified as class 3 using the tool with an E-CAT score of 20.

Case number 3 as discussed above scored 20 points on E-CAT assessment. The majority of the other cases had very good or good agreement within the panel.

Cases 6 and 7 had moderate and poor agreement respectively. The cases are discussed in more details below.

Case	Discussion
	Case 6. Panel achieved moderate to poor agreement in this case, with 1 panel member rating class 1, 21 members reporting it class 2 and 13 members reporting it class 3. This consensus agreed on class 2 which agrees with the ECAT classification and scores ECAT score of 10 points.

Case 7.
Panel achieved poor agreement in this case, with 1 panel member rating class 1, 18 members reporting it class 2 and 16 members reporting it class 3. This consensus agreed on class 2 which agrees with the ECAT classification and scores ECAT score of 11 points.

Cases 6 and 7 as discussed above generated the most debate within the panel. Several comments giving 2/3 as classification initially but settling on one class after being given instruction to only choose one class. These results are in are agreement with the E-CAT score (10-11) bordering on Class 3. The agreement within the panel was much more straightforward with the uncomplicated or more complex cases. When E-CAT score was higher than 15 or less than 4 – excellent agreement was achieved (Kappa 0.9-1.0).

The results from the external validation study show the cases with lowest interclass agreement values where those cases with E-CAT scores ranging between 6-7 or 10-13 points. The feedback obtained from the 35 panel members stressed their need to classify some cases as “in-between” classes. The fact that only three classes were possible to choose from, forced some raters to choose one over the other. Several panel members suggested having an “in-between” class, and the management of such cases depends on the clinicians’ experience and the equipment available for them (magnifications, flexible files etc.).

This limitation can be improved. One solution could be to be more radical and completely abandon the classes system. In this way the value obtained from E-CAT score can be used to describe the complexity of the case. The higher the E-CAT score the more complex the case is. However this approach may be confusing to users if no reference is given. For example, an E-CAT score of 15 is highly complex, but if no guide is given, the value will certainly mean very little for novice users.

Dividing the classes into uncomplicated, moderately complicated and highly complicated was the original aim of this research, and it is likely to be more useful than simply having a value or class number. However, adding the E-CAT score as integral part of this description proved to be useful further information. E-CAT scores of 6 and 11 can both count as moderately complicated. But it is no surprise that a moderately complicated case with an E-CAT score of 6 points is potentially less complicated than that which scores 11, even though this relationship is not "linear".

It therefore seems sensible to suggest either using the E-CAT score as in an indication of how "sub-complex" the case is within the classification. Another approach would be to further divide the classification into 5 classes, similar to the IOTN levels (Brook and Shaw, 1989), adding "moderate-low" complication and "moderate-high" risk of complexities and adverse outcomes as new sub-classification. The suggested revision to the classification would therefore be as shown in table 3-21.

Class	E-CAT score	Terminology and significance
1	0-5	Uncomplicated; low risk of complexity and adverse outcomes
2	6,7	Moderate-low risk of complexity and adverse outcomes
3	8-10	Moderate risk of complexity and adverse outcomes
4	11-13	Moderate-high risk of complexity and adverse outcomes
5	>14	Highly complicated; high risk of complexity and adverse outcomes

Table 3-18 proposed suggestion for the division of endodontic complexity classes into 5 classes rather than 3. This may help identify those "in between" categories as suggested by the panel of endodontists, but may also add further confusion to the ease of use of the tool

When assessing the validity of the tool and comparing the results obtained from the endodontic panel consensus to the results obtained utilising E-CAT achieved perfect agreement for the 15 cases. These results are very encouraging but should be interpreted with caution. Despite having 15 cases being a meaningful sample to derive statistical outcomes, a larger sample of cases may have shown

less than perfect agreement. The number of members on the panel however is believed to be adequate, and little variation is expected with a larger panel. Future research could look into having a similar panel looking into larger number of cases, though financial compensation may be required for the time of the experts for such tasks.

An alternative approach to validate the tool can look into clinically evaluating the sensitivity and the specificity of the tool to prospectively assess endodontic cases. Clinical cases can be assessed with the use of the tool, then a treating clinician could feed back their experience of how complex the case clinically actually was. The challenge would be the subjectivity of what is seen complex by the treating clinician. What is complex to one dentist or endodontist may not be complex at all to another treating dentist or endodontist. The utilisation of 3D-printing to standardise a set number of sample being treated by a large panel of different clinicians could be a further research to improve the validity this tool.

Since further research would require further time and financial cost, it is important to address whether the utility of the Endodontic Complexity Assessment Tool would justify further studies. A study carried out by Fox, Kay and O'Brien (2000) investigated the utility of the IOTN in measuring the value of anterior tooth alignment to adolescents in the UK. The group concluded that it is possible to develop utilities that reflect how patients value the appearance of anterior teeth. When applying this to the context of the current study, further research is suggested to develop utilities that reflect how GDPs, public health commissioners and educational establishment value such assessment tools.

When analysing the reliability study data, the weighted Kappa was found to be 0.80 for the inter-rater and 0.90 intra-rater. This is considered as very good reliability. The agreement ranged from 73% (one participant) to 100% (4 participants) and an average of 90.1% agreement. A study evaluating the reliability of the RIOTN as developed in the RCS guide has been described by (Muthukrishnan et al., 2007) The system was applied to endodontic referrals to a department of restorative dentistry in a district general hospital within a period of one year. In comparison to our

study, intra-rater as well as inter-rater agreement with a consultant in restorative dentistry and a foundation training dentist was assessed. Weighted Kappa for intra-rater agreement was 0.636. Weighted Kappa for inter-observer agreement with a restorative consultant was 0.570 and that for agreement with the foundation training dentist was 0.22.

In a more recent study assessing the reliability of IOTN by dental registrants (Jawad *et al*., 2016) , participants from six different registrant groups were asked to score the IOTN for 14 cases based on study models and photographs as well as completing a short questionnaire. The specialist orthodontists and the qualified orthodontic therapist groups achieved a mean Kappa ≥0.60 indicating 'acceptable' agreement with the expert panel scores. The dental foundation trainee (DFT) and general dental practitioner (GDP) group achieved a mean kappa of 0.20 and 0.22 respectively indicating poor and fair agreement. This study demonstrated lower reliability across different groups of further postgraduate training, and the probability of further knowledge in the topic affecting the reliability of the tool. The 15 dentists who took part in this study were general dental practitioners. Further research is required to assess the reliability of the E-CAT across different registrant groups.

Further analysis of the reliability study results shows that participants seem to have good intra-rater reproducibility when repeating the assessment. However, the most common reasons for not achieving higher inter-rater reliability were the subjectivity of some of the complexity factors when assessed by the observer. The most common reasons for inter-variation across the participants are listed in the table 3.18.

The most common variation (16%) was found to be the interpretation of canal visibility on radiographs. The study clearly demonstrated the variation amongst dentists in what they perceive as clearly visible, sclerotic or invisible canals. In some instances (e.g. case 6) the variation ranged from reporting that the canal was clearly visible to completely invisible across two different participants. The majority however did have reasonable agreement. As all participants were provided with digital radiographs on similar computer screens and the same lighting conditions, it can be inferred that

those variation is due to individual perception rather than other confounding factors (Schriewer *et al*., 2013). However, the degree of variation may vary even further in clinical scenarios with different type of radiographs being available. Conflicting evidence in the literature demonstrated different superiority of digital radiographs verses conventional wet-film radiographs (Ajmal and Elshinawy, 2014, Ki Wei *et al*., 2013). It is no surprise however that different radiographical techniques, angulation, type of films and radiation dose will results in different quality of radiographs for the same clinical case. No research was found to specifically address the effect of the quality of radiographs on canal visibility or clarity of other endodontic complexities. Further research is required to identify the best radiographic protocol to ensure best image outcome for the assessment of preoperative radiographs in endodontic treatment.

The second most common variation was the perceived assessment of root curvature. The participants had the option to choose between, small or no curvature (< 15°), moderate curvature (15 - 40°), severe curvature (> 40°) and extremely severe curvature (> 60°). Most variations occurred between the "small or no curvature" and "moderate curvature" categories (Kappa = 0.67). Severe and extremely severe curvature recorded very good agreement (Kappa = 0.951) in this sample. This result is in agreement with a recent study conducted to evaluate the inter- and intra-observer agreement between training/trained endodontists regarding the ex vivo classification of root canal curvature (Faraj and Boutsioukis, 2017). Periapical radiographs of extracted human posterior teeth with varying degrees of curvature were exposed ex-vivo. Twenty endodontists were asked to classify the root canal curvature into three categories (<10°, 10-30°, >30°), to measure the curvature using the radiographs utilising three quantitative methods (Schneider, 1971, Gu *et al*., 2003) and to draw angles of 10° or 30°, as a control experiment. The procedure was repeated after six weeks. Inter- and intra-observer agreement was evaluated by the intra-class correlation coefficient (ICC) and weighted Kappa were recorded. The inter-observer agreement on the visual classification of root canal curvature was significantly variable (ICC = 0.65, P < 0.018). However, when quantitative methods were used, the inter- and intra-observer agreement on the angle measurements was considerably

better (ICC = 0.76-0.82, P < 0.001) than on the radius measurements (ICC = 0.16-0.19, P > 0.895). The study concluded that visual estimation of root canal curvature was not reliable. The use of computer-based quantitative methods was recommended. The measurement of radius of curvature was more subjective than angle measurement. Those results are consistent with the findings of this study. This calls for the utilisation of a digital approach to build-in a feature within the E-CAT software to allow clinicians to upload an anonymous copy of their radiograph into a secured server to allow the measurement of the curvature angle electronically. Further research for the production of this feature or tool is required.

Other researchers have demonstrated the limitation of the use of periapical radiographs to assess root curvature generally speaking (Patel *et al*., 2010). The angulation of the radiograph, superimposition and the contrast in 2D radiographs are all variables which limit the ability of clinicians to accurately estimate the root curvatures in clinical setting. A group led by (Michetti et al., 2010) demonstrated the advantages of using CBCT radiography as a tool to allow more accurate estimation of root curvature. Considering the relatively higher radiation dose of CBCT, further research is required in this area to evaluate the risks and benefits of such approach to incorporate root curvature assessment as in indication of CBCT to preoperative complexity assessment in endodontics.

Despite the relatively high degree of variation associated with either overstating or understating some complexity factors or slight variation in the information being stated, the results did not seem to significantly be affected in the sample of 15 cases assessed. This is likely to be due to having a range of E-CAT score values, which means a small variation may still yield the correct classification or can be related to this specific sample of cases being assessed.

However, considering the variation obtained above, it is seen possible to improve the reliability of the E-CAT through a more thorough tutorial and calibration process on the use of the tool prior to embarking with case assessments. It has been shown that calibration exercises can significantly

improve the reliability of assessment tool. For example, a study was conducted by an orthodontic group to assess the effect of calibration on reducing subjective bias and standardising criteria for the use of occlusal indices (Richmond *et al*., 1995). The results of that study demonstrated that a group of dentists can easily be trained to record the Aesthetic and Dental Health Components of the Index of Orthodontic Treatment Need (IOTN) and the PAR index to a more satisfactory level. Another study (Hancock and Blinkhorn, 1996) of similar objectives comparing calibrated and non-calibrated users of IOTN showed similar results. This suggests that a calibration process for E-CAT can be done either through sessional courses or an online tutorial or a combination of both. Further research into this topic is required.

In terms of time-efficiency, the average time taken to assess one case was 1 min 33 seconds (M = 1:33, SD = 33 seconds) with range start at 22 seconds (case 5, uncomplicated molar) and up to 3 minute 54 seconds (case 14, complicated molar with perforation). The average time taken for the participants to complete a case improved from 1 minute 36 seconds in the first round to 1:29 seconds in the second round. It is also noticeable that the average time improves in the last 5 cases (1 minute 28 seconds) compared to the first 5 cases (1 minute 40 seconds), suggesting novice operators may take longer to assess the cases compared to experienced users. In comparison to the study done to evaluate the Dutch assessment system (Ree *et al*., 2003a), a larger range of variation was encountered (20-83%). The mean time taken was 3 minutes 46 seconds. The ease of use of ECAT was found to be simple with a mean score of 2.0 using VAS (0 very simple, 10 very difficult) in comparison to VAS mean score of 3.8 utilising the ETC.

The usefulness of assessment tools has varied significantly in the literature. Most of the endodontic assessment tools mentioned earlier were used for clinical decision purposes, referral purposes within the general dentists' community (Ree *et al*., 2003b), some reported to use the complexity forms for fee setting in private practice (Kabir and Mellor, 2004) or for educational purposes in educational establishments to identify the level of complexity for undergraduate and postgraduate

trainees (AAE, 2005b). Considering the improved results obtained using the E-CAT in terms of its reliability, validity and time-efficiency, this thesis supports its use for all the purposes mentioned above. The summary page provided at the end of each E-CAT assessment can also be used for dental record keeping as tangible evidence to show the clinicians systematic assessment and consent process.

In the United Kingdom, some assessment or treatment need tools are incorporated into public health domains. For instance, the IOTN was first piloted as a public health tool in 1993 (Lunn *et al*., 1993) which suggested its usefulness in that domain following some modifications. It became more of a commissioner tool and a contractual requirement in the NHS in England and Wales since the introduction of the new contract dental contract in 2006 (Jawad *et al*., 2015). Whether the E-CAT can be used in similar manner is a question that requires further research to address its clinical relevance and any modification that may be required prior to that transformation.

In order to clarify the value of risk assessment tools, it is imperative to explain the tangible implications of the classes and their meanings. It is important for all users to understand that a certain class of complexity level as indicated by the E-CAT does not directly reflect which clinician (general dentist, DWSI or specialist) should be treating the case. The purpose of those classifications is rather to indicate the level of risk of potentially encountering difficulty while treating that particular case, or indeed the risk of generating adverse outcomes. A case that is classified as "uncomplicated" has a low risk of encountering difficulty or causing adverse outcomes if treated. However, there is still a low probability of those happening. On the contrary, a highly complicated case has a high risk of adverse outcome being encountered, but there is still a chance, be it a small chance, it may be treated by a general dentist with no further qualifications without encountering real difficulty or adverse results. The intention is therefore for the user to use their judgement, given the level of risk indicated, whether they would feel comfortable to accept it, or refer it on, in order to offer their patients the best possible treatment outcome.

This research helped defining the type of non-surgical root canal treatment cases which can be classified as uncomplicated or having low risk of adverse outcomes, but did not look into the distinction of level of competence or qualifications required to confidently manage moderately and highly complicated cases. Further research into this topic will be required.

3.5 Conclusion

In comparison to the existing data of the assessment tools available in the literature, the E-CAT appears to fulfil the study aim of developing a more predictable, more reliable, time-efficient, user-friendly tool and helped defining the meaning of “uncomplicated” non-surgical endodontic treatments. The null hypothesis was therefore rejected.

However, this part of the study demonstrated that despite best efforts, the development of a perfect and 100% accurate tool at all times to assess endodontic complexity is at best extremely challenging, if not impossible. Further research is required to further validate the E-CAT’s clinical relevance, evaluate its sensitivity and specificity in identifying complex endodontic cases in a clinical setting, and finally produce a more scientific guide on the degree of competence and training required to tackle the different classes of complexities assessed.

CHAPTER 4 : THE PREVALENCE OF ENDODONTIC COMPLEXITY IN GENERAL DENTAL PRACTICE

4.1 Introduction and Aims

As can be seen from the previous chapters, the scope of endodontic treatment can significantly vary in its complexity owing to numerous factors and conditions. There are several cross-sectional studies describing the prevalence of periapical radiolucency in the population, a surrogate of necrotic pulp disease. In addition, there are other studies looking into the prevalence of root canal treatment within the population. However, probably due to "complexity" being a subjective issue, there does not appear to be any attempt in the literature to identify the prevalence of complex treatment or the reasons behind such complexity.

A South Korean study made an attempt to determine the most common endodontic complexities encountered by general dentists through a study of referral reasons to endodontic practices (Kim, 2014). The most common referral reasons were found to be persistent pain and presence of a sinus tract following primary RCT. Most common clinical reasons were found to be canal calcification, broken instruments and posts.

In order to collect information related to the factors influencing root canal treatments complexity, there needs to be a way of identifying those factors then classifying them, and then a mechanism to gather the information from the population. The development of the Endodontic Complexity Assessment Tool E-CAT (Chapter 3.2) required thorough research of the factors affecting endodontic complexity, hence why the E-CAT itself, following its validation in the previous chapter, may be able to serve the purpose of collecting information, rather than relying on the existing paper format tools.

General dentists have, and most probably, will always provide the majority of root canal treatments within the population. The numerous complexity factors, however, will cause GDPs to refer some

cases to endodontic specialists. The outcomes of endodontic treatment carried out by endodontists compared to those by general dental practitioners seem to be higher in most reports (Imura *et al*., 2007, Ng *et al*., 2008).

There have been no studies reporting on the prevalence of complex endodontic cases in general dental practice. In addition, there is currently no data on the levels of endodontic complexities or specific complexity factors could affect the clinical decision of the proposed treatment to the case being assessed. For example, it is unknown whether a highly complicated root canal treatment, or teeth with severe root curvature, are more likely to be extracted, referred to secondary care or treated in general practice. Such information may help identifying shortfalls, if any, within the health system and help guiding future research to resolve such areas.

This gap in the knowledge of complexity prevalence indicated the need for this study. The results may be used in several applications to assess the level of need for endodontic training and commissioning required. Without such information, it is difficult to estimate the number of endodontic specialists or the level of advanced training necessary within the public health system. It is also difficult for educational establishments to tailor their endodontic training to target the most prevalent complexities and the level at which this training is provided.

Electronic surveys are becoming increasingly more attractive with the advancement of information technology and the availability of electronic devices (Dillman and Smyth, 2007). Pop-up windows combined with visual and audio aids providing additional information may be added to clarify responding in those surveys, which would have been much more difficult to implement in paper-format questionnaires. Electronic surveys can be programmed to automatically analyse and present the data in a much more user-friendly format. However, the issues with web-based epidemiological studies usually concern practicality and data safety. A study looking into those issues concluded that many of those problems related to the use of web-based questionnaires have been solved, but each case needs to be approached individually (van Gelder *et al*., 2010).

This chapter is therefore concerned with attempting to identify the prevalence of endodontic complexity utilising the endodontic complexity assessment tool as an electronic survey platform.

Aims

This study was designed to assess the prevalence of non-surgical root canal treatment complexity in general dental practice, to help assess the level of need for advanced endodontic treatment within the health system.

The objectives of this study were as follows:

1. Determine the prevalence and distribution of the factors influencing endodontic complexities in general dental practice.
2. Determine the overall prevalence of class I,II and III (uncomplicated, moderately complicated and highly complicated) non-surgical root canal treatment in general dental practice
3. Assess the distribution of proposed dental treatment (NSRCT, referral or extraction) in relation to the complexity levels and factors.

4.2 Methodology

4.2.1 Ethical Approval

As this part of the study required access to anonymised clinical data and indirect access to patient-related information, an application was submitted through the Integrated Research Application System (IRAS) prior to the launch of the study in order to obtain research ethical committee approval for the process. The committee was of favourable opinion to the design of the study, and approval was granted on 30th October 2015 (REC reference: 15/NE/0372). A copy of the protocol was also submitted to the local Research and Development team (RND) for assessment and hospital's sponsorship for the study was gained.

4.2.2 Sample size calculation

In order to collect the data required, recruitment of general dental practitioners practicing in the United Kingdom was essential. Statistical advice was sought to assess the required number of cases required to provide a meaningful prevalence study. Extrapolating from the prevalence studies conducted on similar topic (Pak *et al*., 2012, Hebling *et al*., 2014), a sample size of around 300-400 endodontic cases would be required.

Assuming an infinite number of population (>100,000) to determine the appropriate sample size for estimating the proportion of the population that possesses a particular endodontic complexity with 95% confidence interval (CI= 95%), the sample size was calculated using the following formula

Sample size is calculated using the formula:

$$\text{Unlimited population: } n = \frac{z^2 \times \hat{p}(1-\hat{p})}{\varepsilon^2}$$

Where z is the z score, ε is the margin of error, N is population size, p̂ is the population proportion.

The total number required was calculated to be 385.

4.2.3 Participants recruitment

An advert on several platforms including dental online forums and dental societies (GDPUK, D4D and UK Dentists groups) was published inviting dentists to volunteer for this part of the study.

The inclusion criteria were defined as general dental practitioners (GDP) working full time in general dental practice in any of the United Kingdom regions. Cases treated by specialist endodontists or dentists with special interest in endodontics who accepted dental referrals were excluded from the study. Practice management approval was sought prior to accepting the participant into the study. A total of 30 GDPs of variable demographics across the United Kingdom were recruited.

4.2.4 Data collection

Utilising the digital nature of E-CAT version 2.0, the computer programmers designed to incorporate a password protected and secure feature to tool to enable the GDPs inputting their data into the tool which is then recorded into a secure database.

The information recorded included cases encountered with the complexity criteria as shown in table 4.1.

Surveyed categories of endodontic complexities
○ Pre-treatment prior to commencement
○ Radiographic difficulties
○ Medical history, anaesthesia and patient management
○ History of trauma
○ Diagnosis
○ Physical and psychological limitations
○ Mouth opening
○ The position of the tooth
○ Inclination and rotation of tooth
○ Crown morphology and presence of extra-coronal restoration
○ Access to root canal system
○ Root curvature
○ Root canal morphology
○ Apical morphology
○ Canal radiographic visibility
○ Previous endodontic treatment
○ Iatrogenic incidents
○ Root resorption
○ Perioendo (Periodontic-Endodontic) lesion involvement

Table 4-1 showing the surveyed categories of endodontic complexities as recorded by the endodontic complexity assessment tool

In addition to the criteria mentioned in the table 4.1, the participants were also asked to report on the outcome of the cases assessed; whether they were treated in general dental practice, referred to a dentists with special interest in endodontics, private endodontist, secondary NHS hospital care or extracted.

Each participating dentist was requested to include and record 10-15 consecutive cases where endodontic treatment was indicated as a treatment option. Using the tool all the responses were anonymised, no patient data was required or included. The dentists had 4 months to complete their data collection.

Prior to starting the study, every participant was contacted either through email or phone and was given an overview of the tool and its functionality in addition to the Participant Information Leaflet (PIL) (attached in appendix). They were then calibrated through a series of 5 anonymised endodontic cases provided to them. When a participant did not achieve a 100% calibration initially, a series of 5 further cases were sent to them with the relevant advice until 100% calibration was achieved.

All recruited cases were included regardless of whether patients chose to receive treatment or not. The cases where patients chose to extract their tooth instead or defer the treatment for personal or financial reasons (e.g. cannot afford treatment or referral) were included. Cases where pulp extirpation was done or the case was referred to secondary care or private specialist were also included.

The participating GDP's GDC number, qualification year, practice address and nature of practice (NHS or private) were recorded on a secure password protected database. In order to ensure the accuracy of the data, each GDP was provided with a personal identification number (PIN) code to match their details when the data were recorded. Without the PIN, no data could be entered onto the research database.

The prevalence of individual complexities were analysed and the prevalence of the three endodontic classifications were assessed utilising the tool programming as encountered by GDP in general dental practice.

This study did not include any patient-related personal information. The collected information was stored on a password encrypted database. The data was reviewed in a secured environment at The University of Liverpool.

4.2.5 Funding

The development of E-CAT was awarded a grant from the European Society of Endodontology to assist in the development and programming of the tool and host it on a secure permanent server. In addition small monies were sought from the DDSc research fund (Restorative Department) that were used to buy appropriate stationary for the patient information leaflets, and consent or assent forms. The RLUBH sponsored the research throughout its conduct period.

4.3 Results

4.3.1 Participants and total number of data collected

A total of three adverts were sent out. Overall, 44 general dentists responded to the adverts, of which 30 were successfully enrolled onto the study. A total of three dentists were excluded due to working in a hospital environment, a further two were only accepting endodontic referrals, five did not complete the calibration exercise and the remaining four did not contribute with cases following their enrolment.

The demographic distribution of the participants were as follows

Participants demographic data	Distribution (*N=30*)
Gender	
Male	21
Female	9
Location	
London and South of England	5
Midlands	5
North West	10
North East	4
Scotland	3
Wales	3
Post graduate endodontic training	
Yes	8
No	22
Practice type	
NHS	19
Private	11
Post qualification experience (years)	
0-5	10
5-10	9
10-15	6
15+	5

Table 4-2 Showing the participants demographic data of gender, location post graduate endodontic experience, practice type and years post qualification.

Collectively, the GDPs input a total of 437 non-surgical endodontic cases onto the E-CAT database. Two dentists reported two separate mistakes in their input via email. Those two results were deleted leaving a total of 435 cases.

On average the GDPs required on average 6.25 weeks (pro rata; taking part-time working dentists and those who took annual leave) to complete collecting 10 cases, the range was a low as 4 weeks and up to 11 weeks leading to the assumption of full-time GDPs to have an average of 1.6 potential root canal treatment a week. The summary is shown in table 4.3.

Potential RCTs encountered per GDP	Per week (range)	Per annum (range)
Average (n)	1.6 (0.9-2.5)	70.4 (39.6- 100)

Table 4-3 showing the average numbers of root canal treatments encountered by a GDP practicing in the UK (full time). The average number of potential RCT encountered by a GDP practicing in the UK taking into account bank holidays and annual leave.

4.3.2 Prevalence and distribution of complexity factors

In total, 435 non-surgical root canal treatment cases were assessed and recorded. All cases were based in general dental practice and excluded any referral cases.

The results showed relatively equal distribution of posterior and anterior teeth potentially requiring root canal treatment. Root canal retreatments formed a relatively high number (22.9%) of the cases encountered. The majority of the cases (64.4%) appeared to have <15^{o} root curvature, 30.6% had 15-40^{o} curvature and only 4.1% had > 40° curvature. Teeth with existing extra-coronal restorations formed 18% of the cases encountered.

Radiographically, visible and moderately reduced canal space was reported in 76.9% of the cases, while 20.9% had severely reduced canal space and only 3.2% were perceived to have invisible canal space. History of trauma was encountered in 9.0% of the evaluated cases.

Tables 4.4 - 4.7 below show the distribution of the data recorded in endodontic cases in general dental practice.

Factors/categories	Number of entries (N=435)	Prevalence within general practice
Tooth position		
Anterior or Premolar	207	48.6%
1st or 2nd Molar	222	50.2%
3rd Molar	6	1.2%
Root curvature		
Small or no curvature (< 15°)	282	64.4%
Moderate curvature (15 - 40°)	133	30.6%
Severe curvature (> 40°)	18	3.5%
Extremely severe curvature (> 60°)	2	0.5%
Canal radiographic visibility		
Large pulp chamber and clearly visible canals to apex	148	34.3%
Reduced pulp chamber volume , narrow yet visible canal space to apex	182	42.6%
Indistinct pulp chamber or canal space in part or throughout	91	20.9%
Completely invisible canal space in part or throughout	14	3.2%
Mouth opening		
Normal mouth opening (>35mm)	406	93.4%
Reduced mouth opening (25-35mm)	26	5.9%
Extremely reduced mouth opening (<25mm)	3	0.7%
Inclination of tooth (degree of tooth tilt)		
No or small inclination (< 10°)	379	87.1%
Moderate inclination (10 - 35°)	52	12.0%
Extreme inclination (> 35°)	4	0.9%

Table 4-4 showing the prevalence and distribution of numerous factors which may potentially affect the complexity of non-surgical root canal treatment

Factors/categories	Number of entries (N=435)	Prevalence in general practice
Radiographic difficulties		
Normal conditions	413	94.9%
Severe gag reflex	6	1.4%
Narrow or low palatal vault or High floor of mouth	12	2.8%
Hard to solve superimposed anatomical structure	4	0.9%
Medical history, anaesthesia and patient management		
No medical problem or well controlled MH - ASA Class II	412	94.7%
Diabetes (poorly controlled)	7	1.6%
Complex MH ASA III or VI including Haemophilia	6	1.3%
Vasoconstrictor intolerance	1	0.3%
IV bisphosphonate or history of head and neck radiotherapy	9	2.0%
Allergy to anaesthesia	0	0%
Diagnosis		
Uncomplicated clear diagnosis	386	88.9%
Other adjacent teeth could be involved. Requires simple further investigation	40	9.1%
Confusing and complex signs of symptoms: difficult or unable to achieve clear diagnosis	9	2.0%
Rotation of tooth		
No or mild rotation (< 10°)	413	94.9%
Moderate rotation (10 - 35°)	21	4.8%
Extreme rotation (> 35°)	1	0.3%
Apical morphology		
Closed (fully formed) apex	424	96.5%
Open apex (> size 60 k-file)	9	2.1%
Open apex with history of failed surgical retrograde root end fill	2	0.4%

Table 4-5 showing the prevalence and distribution of numerous factors which may potentially affect the complexity of non-surgical root canal treatment

Factors/categories	Number of entries (N=435)	Prevalence in general practice	Prevalence within category
Pre-treatment prior to commencement	143	32.9%	
Simple pre-treatment required for isolation (e.g. supra-gingival caries, restoration replacement)	73	16.7%	51%
Extensive pre-treatment required for isolation (e.g. sub-gingival caries, margin elevation)	37	8.5%	25%
Removal of crown or bridge prior to treatment	33	7.5%	24%
Obstructed access to root canal system with direct restorations	282	64.8%	
Direct restoration with clear crown morphology	119	27.3%	42%
Direct restoration affecting crown morphology	142	32.6%	50%
Amalgam core build-up in pulp chamber without post or crown	10	2.3%	4%
Composite core build-up in pulp chamber without post or crown	11	2.5%	4%
Extra-coronal restoration	80	18%	
Crown, bridge or onlay present but planned to be removed prior to commencing treatment	35	8.0%	43%
Access required through crown or onlay	37	8.5%	46%
Poorly adapted post	4	0.9%	5%
Well adapted and firmly cemented post/cast post and core	4	0.9%	5%
Previous endodontic treatment	101	22.9%	
Previously initiated but not obturated, endodontic treatment	33	7.5%	32%
Canal(s) sub-optimally obturated with gutta-percha	58	13.3%	58%
Canal (s) well-obturated with gutta-percha or obturation is >2mm overfilled	5	1.1%	5.0%
Canal(s) obturated with other materials (e.g. Silver cones, resin based filling, bioceramic material)	5	1.1%	5.0%
Iatrogenic incidents	26	5.9%	
Supra-osseous perforations	3	0.6%	11%
Sub-osseous perforations	2	0.4%	7%
Separated instrument: clinically visible	3	0.6%	11%
Separated instrument: clinically not visible	5	1.1%	19%
Overt ledge or apical transportation	10	2.2%	38%
Significantly misaligned previous endodontic access	3	0.6%	11%

Table 4-6 showing the prevalence and distribution of numerous factors which may potentially affect the complexity of non-surgical root canal treatment

Factors/categories	Number of entries (N=435)	Prevalence in general practice	Prevalence within category
Root resorption	16	3.6%	
Apical root resorption	10	2.2%	58%
Internal root resorption	5	1.1%	24%
External root resorption	3	0.7%	18%
Complex root canal morphology	51	11.7%	
Very long tooth (working length> 30mm)	1	0.3%	2%
Anterior tooth or lower premolar with 2 canals	7	1.6%	14%
Premolar with 3 canals	3	0.69%	6%
Molar with ≥ 4 canals	40	9.2%	78%
Crown Morphology abnormality	4	0.9%	
Dens invaginatus or fusion	3	0.7%	75%
Dentinogenesis imperfecta	1	0.3%	25%
History of trauma	39	9.0%	
Unknown type of trauma in the past	17	3.9%	43.3%
Uncomplicated crown fracture	4	0.9%	10.0%
Root fracture	1	0.3%	2.5%
Concussion	7	1.5%	17.9%
Complicated crown fracture of mature teeth	6	1.3%	13.8%
Subluxation	1	0.3%	2.5%
Complicated crown fracture of immature teeth	1	0.3%	2.5%
Severe luxation or avulsion	2	0.5%	5.0%
Root canal shape and pulp stones	62	14.3%	
Pulp stones present	38	8.7%	61.3%
S shape canal	21	4.7%	33.9%
C shape or ribbon shape root canal system (confirmed clinically or with CBCT)	3	0.6%	4.8%
Physical and Psychological limitations	64	14.7%	
Lack of cooperation or significantly nervous patient	47	10.9%	74%
Patient requires sedation	4	0.9%	6%
Moderately limited reclination	9	2.3%	14%
Unable to recline	4	0.9%	6%
(Periodontic-Endodontic) lesion involvement	34	7.8%	
Perio-endo lesion	19	4.3%	56%
Furcation involvement	7	1.6%	21%
Mobility, fenestrations or dehiscence	7	1.6%	21%
Root resection/hemi-section expected or completed	1	0.3%	3%

Table 4-7 showing the prevalence and distribution of numerous factors which may potentially affect the complexity of non-surgical root canal treatment

4.3.3 The overall prevalence and distribution of complexity classes in general practice

The distribution of the classes across the three endodontic complexities is shown in table 4.8. Uncomplicated cases or those with low risk of complications were relatively more prevalent than those of 2 then 3 respectively. The distribution of complexity over classes 1, 2 and 3 was found to be 39.8%, 31.9% and 28.3% respectively.

Class	Number (N= 435)	Prevalence (%)
Class 1 (Uncomplicated)	173	39.8%
Class 2 (Moderately complicated)	139	31.9%
Class 3 (Highly complicated)	123	28.3%

Table 4-8 the overall prevalence of class I, II and III (uncomplicated, moderately complicated and highly complicated) non-surgical root canal treatment in general dental practice.

4.3.4 The distribution of proposed dental treatment in relation to the complexity levels and factors

To further analyse the results and enable more meaningful interpretation, the study also looked into assessing the proposed treatment destination of each case encountered. The results are shown in table 4-9 below.

Classes/outcomes	Number of entries	Distribution (%)
All cases	(N=435)	
RCT in general dental practice	244	60%
Treatment to dentists with special interest in endodontics	28	6%
Referred to a private specialist in endodontics	22	5%
Referred to NHS hospital or secondary care	43	9%
Extraction	77	18%
Patient still undecided	11	2%
Class 1	(N=173)	
RCT in general dental practice	148	85.4%
Treatment to dentists with special interest in endodontics	3	1.9%
Referred to a private specialist in endodontics	0	0%
Referred to NHS hospital or secondary care	4	2.3%
Extraction	16	9.3%
Patient still undecided	2	1.1%
Class 2	(N=139)	
RCT in general dental practice	83	59.7%
Treatment to dentists with special interest in endodontics	13	9.5%
Referred to a private specialist in endodontics	7	5.0%
Referred to NHS hospital or secondary care	9	6.5%
Extraction	22	15.8%
Patient still undecided	5	3.5%
Class 3	(N=123)	
RCT in general dental practice	23	18.8%
Treatment to dentists with special interest in endodontics	12	9.7%
Referred to a private specialist in endodontics	15	12.2%
Referred to NHS hospital or secondary care	30	24.4%
Extraction	39	31.7%
Patient still undecided	4	3.2%

Table 4-9 showing the distribution of proposed dental treatment in relation to the complexity levels across the three complexity classes

The variation in the proposed dental treatment in relation to the complexity levels is shown in figure 4.1. A decreasing proportion of treatment in general practice can also be observed the higher the complexity level.

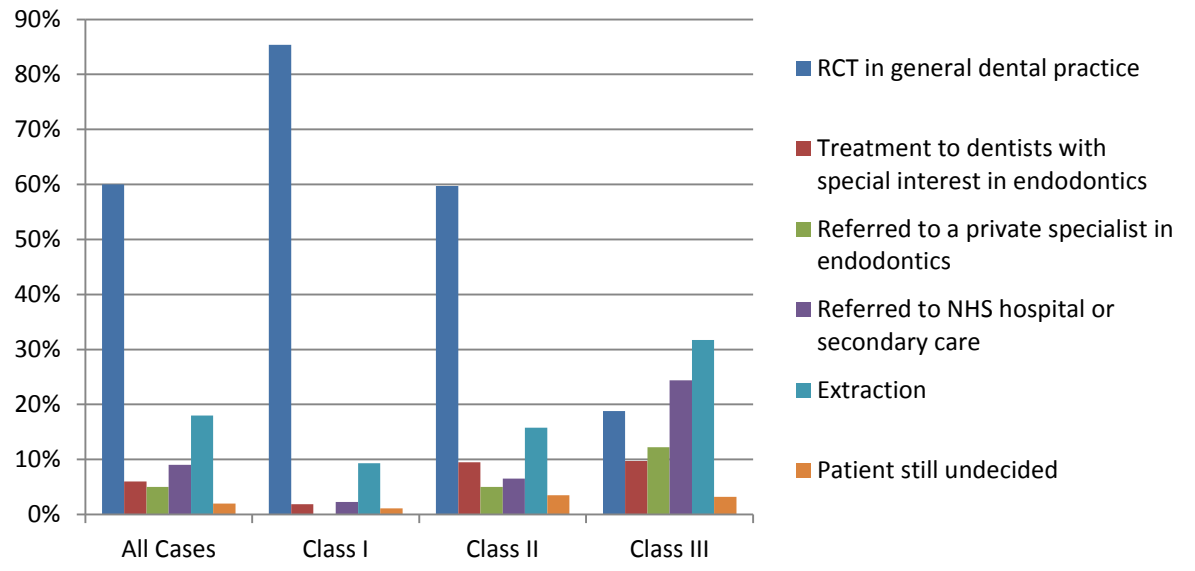

Figure 4-1 shows the trends of proposed dental treatments in relation to the complexity levels. An upward trend can be clearly seen for tooth extraction in relation to the complexity, as well as upward trends for the referrals.

The distribution of proposed treating clinicians in relation to the type of tooth (anterior or posterior) being assessed for treatment. This is shown in table 4-10 below. Despite relatively equal distribution of cases encountered with potential root canal treatment across anterior and posterior teeth, the proposed treatment of extraction for posterior teeth is double that of anterior teeth..

Classes/outcomes	Number of entries	Prevalence
Anterior teeth (including premolars)	(N=207)	
RCT in general dental practice	127	61.3%
Treatment to dentists with special interest in endodontics	16	7.7%
Referred to a private specialist in endodontics	7	3.5%
Referred to NHS hospital or secondary care	28	13.4%
Extraction	22	10.6%
Patient still undecided	7	3.5%
Posterior teeth (1st and 2nd molars)	(N=222)	
RCT in general dental practice	120	53.9%
Treatment to dentists with special interest in endodontics	22	9.8%
Referred to a private specialist in endodontics	14	6.3%
Referred to NHS hospital or secondary care	9	4.2%
Extraction	53	23.8%
Patient still undecided	4	2.0%

Table 4-10 showing the distribution of proposed dental treatment in relation to the anterior and posterior teeth

The results in the table 4-11 show the distribution of proposed treatment outcomes in relation to cases with failed endodontic treatment (previously obturated cases). A relatively high percentage of previously root canal treated teeth are either referred secondary care or extracted in general practice.

Classes/outcomes	Number of entries	Prevalence
Failed RCT (previously obturated)	(N=68)	
RCT in general dental practice	14	20.6%
Treatment to dentists with special interest in endodontics	6	8.8%
Referred to a private specialist in endodontics	4	5.9%
Referred to NHS hospital or secondary care	16	23.5%
Extraction	22	32.4%
Patient still undecided	6	8.8%

Table 4-11 showing the distribution of proposed dental treatment in relation to history of previous endodontic treatment

The trends can also better demonstrated utilising column chart as shown in figure 4-2.

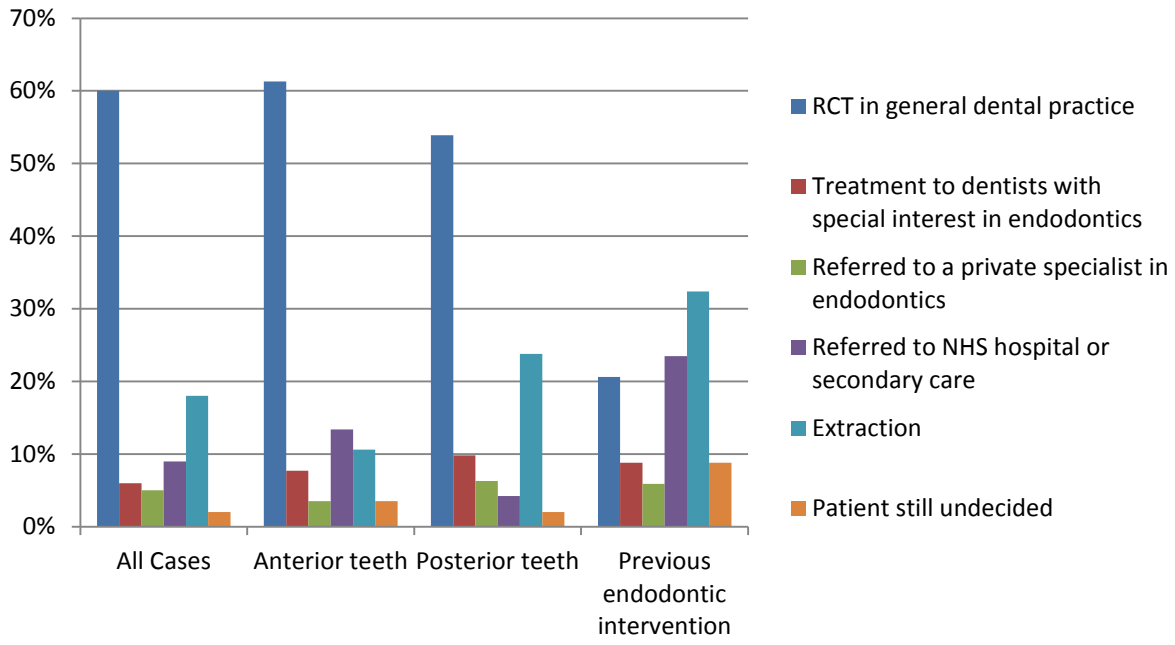

Figure 4-2 shows higher proportion of teeth being extracted observed in relation to posterior teeth and teeth with previous endodontic intervention.

4.4 Discussion

This cross-sectional epidemiological study was designed to explore the prevalence of the factors influencing the complexity of non-surgical root canal treatments in general dental practice.

The study adopted an electronic and digital approach to collect the data. Several studies have discussed the potential benefits and disadvantages of web-based surveys and the ongoing developments in the area (van Gelder *et al*., 2010). Conventional methods to gather information from study subjects, including face-to-face, traditional paper and-pencil format questionnaires and telephone interviews are increasingly failing to generate high-standard qualitative results within the financial parameters given. Web-based surveys are now frequently used in marketing research and psychological studies, but their use in epidemiological studies was merely 1% in published articles (Ekman and Litton, 2007).

There have been a few examples of successful studies conducted using the electronic surveys approach and are already available, including Danish Web-based Pregnancy Planning Study (Mikkelsen *et al*., 2009), the Millennium Cohort Study (Smith *et al*., 2007) and the Nurses and Midwives e-Cohort Study (Turner *et al*., 2009). Those studies succeeded to collect a large sample number through electronic surveys with meaningful results.

An ideal epidemiological study would include a very large sample with as much detail of each category recorded as possible. The data collection would ideally be standardised through a series of examiners cross-checking the records to ensure minimal bias or human error occur in recording the data. In the case of single item prevalence study (e.g. periapical pathology), this is relatively easily achieved. In contrast, the current study required a comprehensive assessment of root canal treatment complexity consisting of numerous interdependent factors; including patient-related factors, tooth related factors and several other miscellaneous factors. Therefore, determining the prevalence of the root canal treatment complexity was found to be challenging and demanded that all relevant factors were recorded or accounted for in as much detail as possible.

Since the development of E-CAT required a thorough research of the factors affecting endodontic complexity, the process of ensuring most of the key factors are included within the surveying questions became more achievable.

The data entry needed to be as accurate as possible in order to ensure meaningful results. Since the nature of this epidemiological study required a national multi-centre design, it was found exceedingly challenging to have the same examiners going into each centre to record the data. The challenges included the prospective nature of the study, requiring the patient to be present for assessment, the frequency of non-surgical endodontic treatment in general dental practice, the financial aspect of examiners travelling to each centre and most importantly patients' confidentiality.

In order to ensure practical methodology is followed, maintaining accurate results, only fully qualified dentists with good knowledge of the factors recorded in the assessment criteria were selected. However, despite best efforts, it must be acknowledged that the areas where clinician's subjective opinion may vary (e.g. root curvature, radiographic canal visibility); the results record may also vary. This should be taken in consideration while analysing these data. In an attempt to dilute the effect of these subjective variations, the number of dentists participating, and the number of cases collected was aimed to be as high as possible. A calibration process was also implemented and aimed to ensure all dentists had similar views of how to use the tool and when to record each criterion prior to their recruitment. Example of radiographs showing root canal visibility calibration and Schneider's technique, as described in (Gu et al., 2003), of measuring root canal curvature were provided. On the other hand, the majority of the factors reported (e.g. medical history, presence of previous endodontic treatment or indirect restorations) were less subjective. The reliability of these results can be expected to be very good.

Overall, a total of 30 GDPs were recruited. The demographic distribution of those provided a reasonable representing sample. The number of dentists participating in the North West was higher

than that of the other regions in the country. This is likely to be due the University of Liverpool being in the region and the dentist feeling more affiliation or willing to "give back" to the teaching hospital when invited. The distribution between NHS and private was reasonable given the fact there are more NHS practices in UK than there are private (BDA, 2013). A higher number of the dentists within their first 10 years of qualification took part in the study compared to those who graduated longer than 10 years in their career. This can probably be explained due to the lifestyle of younger dentists wishing to take part in an electronic study with new tool and still wishing to keep in touch with their dental research side. However, this variation was still reasonable with at least 5 dentists representing each category.

Demographically, it was expected that dentist with special interest in endodontics would be more inclined to take part in this research given the nature of the topic being explored. In order to ensure a more equal and unbiased distribution of general practice, the participants were asked to declare any formal post graduate training in endodontics. The sample obtained showed about 25% only of the participants had attended post graduate training courses (ranging from day courses to Postgraduate Diploma) in endodontics. None of the participants included any referral cases onto the study.

Overall, the majority (71%) of the root canal treatments encountered in general dental practice was found to be either uncomplicated (class I) or moderately complicated (class II) and can be considered within the remit of general dental practitioners. This is based on the assumption that class 2 complexity cases carry a moderate risk of complication but may still be within the remit of an experienced general dentist or dentists with further non-specialist training in endodontics. However, a relatively high proportion (29%) of the cases was found to be of higher complexity and carry higher risk of complications and therefore ideally requires specialist input. As discussed in the previous chapter, the boundaries between what specialists and dentists with enhanced skills are expected to treat is a topic that requires further research in itself and was beyond the remit of this study.

The results of the current investigation provided new insight into the prevalence of the radiographic canal visibility, where visible and moderately reduced canal space was reported to be 76.9% of the cases, while 20.9% had severely reduced canal space and only 3.2% were perceived to have invisible canal space. These results must not be confused with the prevalence of sclerotic canals. The periapical radiographs used in the study may not be sensitive enough to deduce this conclusion (McCabe and Dummer, 2012). It is imperative that the limitations faced in developing the endodontic complexity assessment tool previously discussed in chapter 3.4 are discussed again here. The subjectivity of assessing the canal radiographic visibility and the variation in root curvature assessment are implicated again in this study. Although the results can provide us with a good insight of the prevalence of reduced radiographic canal space and curved roots, the true prevalence of those values can vary due to the use of 2-dimesntional radiographs in the assessment of the endodontic cases. The observer variation in the assessment of root curvature, the angle of the radiograph, and the method used to measure the curvature may also result in variation from the true prevalence of anatomically curved canals to the results recorded here. It might be more accurate to state that the results concerning the prevalence of canal visibility and root curvature recorded in this study reflect their perceived prevalence by general dental practitioners in the UK rather than the true value.

The prevalence of severe root curvature was lower than anticipated at only 4.1% having > 40° curvature. The majority of the cases (64.4%) appeared to have <15^{o} root curvature with 30.6% exhibiting a 15-40^{o} curvature and. The Schneider, Weine, Lutein and Cunningham's methods of evaluating root curvature as summarised in (Balani et al., 2015)) were all considered for the purpose of the study. As the Schneider techniques was found to be the most commonly familiar and easier to follow (Gunday *et al*., 2005), it was selected for this research despite the limitations associated with it.

History of trauma accounted for approximately 9% of the cases requiring non-surgical root canal therapy. No other observational study was found reporting on similar findings or the proportion of root canal treatment required for adult patients as consequence of dental trauma in general practice in the UK. On the other hand, a review study looking into the overall prevalence, aetiology and consequences of dental trauma reported the prevalence varying in different countries and different age groups ranging from as little as 4.9% and up to 33% (Zaleckiene *et al*., 2014). In adults, self-reported trauma was found to be in the region of 15% (Locker, 2007). A Swiss study reported a total of 23,000 insurance recorded injuries of 2 years in a population close to 8 million people (Brunner *et al*., 2009). The authors reported that most trauma recorded did not require immediate root canal treatment or advanced dental treatment.

The findings in the current study reported on all potential RCT cases where dental trauma was previously encountered on the tooth, but no distinction was made whether the RCT was required as a direct consequence of the trauma or not. These results should therefore be interpreted accordingly.

Cases with history of previous endodontic intervention formed a relatively high number (22.9%) of the potential root canal treatments encountered in general dental practice. Interestingly, around 60% of those cases were perceived to have sub-optimally obturated root canals with gutta-percha and only 5% with good obturations. The remaining 35% were either extirpated unfilled teeth or cases with non-standard root canal obturation. These results may indirectly be linked to the classic studies reported by (Sjogren et al., 1990) and (Ray and Trope, 1995) on the relative importance of achieving good obturation in relation to other factors such as coronal seal. However the information provided in the study does not provide us with sufficient details to draw further conclusions.

The proportion of teeth with class 3 complexity and those with previous endodontic intervention being extracted was significantly higher than those previously unfilled. The exact reasons behind this decision in treatment planning were not recorded as part of study. It was found that only 20% of the

cases with previous endodontic treatment would get planned for treatment in general dental practice. This study also shed the light on the higher tendency of posterior teeth being extracted in relation to anterior teeth. May one speculate this could be due to their higher complexity or to do with dentists adopting the shortened dental arch approach as described by Kaysar (1981).

Despite the results identifying trends for more complex cases exhibiting higher probability of being extracted, this study was not designed to provide the information behind the reasons influencing this decision. These can be due to patients' wishes, financial limitations, shortage of referral service, clinicians perceived long term outcome or indeed various other factors. Further research is required to further explore this topic.

Nevertheless, regardless of the underlying motives, as the health system in the UK is facing a more aging population (Thomson and Ma, 2014), the trend of extracting potentially saveable teeth with higher complexity root canal treatment will still have its significant implications. These may include the effect on the older patients' oral-health-related quality of life and the increase of the restorative burden within the health systems. In their systematic review, (Gerritsen et al., 2010) demonstrated fairly strong evidence that tooth loss is associated with impairment of OHRQoL and that the location and distribution of tooth loss affect the severity of the impairment. An anterior tooth loss was found to have the highest impact on oral-health-related quality of life (OHQoL). This may explain the trend of higher extractions rate in posterior teeth than anterior teeth found in results of this study.

The provision and the long-term maintenance of extracted teeth replacements, being dentures, bridges or implants, could potentially be less cost effective than the provision of root canal treatment. In a relatively recent study utilising Markov model, Pennington and his group (Pennington *et al*., 2009) found that root canal treatment is highly cost-effective as a first line intervention. Orthograde re-treatment was also found to be cost-effective with implants having a role as a third line intervention if re-treatment fails. Further research is required in this field to

assess the potential opportunities in improving the overall healthcare in reducing the extraction rate of teeth which could potential be endodontically treated.

Teeth with existing extra-coronal restorations formed 18% of the cases encountered. The results also demonstrated a high tendency of the surveyed general dental practitioners to provide the root canal treatment through the existing extra-coronal restoration rather than replacing it. Of those cases recorded with an extra-coronal restoration, only 48% were planned for removal, while 52% were planned for root canal treatment through the existing crown or bridge. The debate of replacing extra-coronal restorations or not prior endodontic treatment has been long discussed among clinicians. A study by (Abbott, 2004) found a very high chance (44%) of missing caries, cracks or marginal breakdown diagnosis prior to restoration removal. They recommended that all restorations should be removed prior to endodontic treatment in order to remove the common factors that may have caused the pulp and periapical disease, and to assess the tooth's prognosis and future treatment needs. Further research is required to assess the reasons behind general practitioners still wishing to access the tooth through extra-coronal restorations and whether this truly has an impact on the long term prognosis of and treatment outcome of endodontic treatments.

It must also be acknowledged that despite the participants all being qualified dentists and calibrated for the study, the study design did not allow for cross-examination of the data to double check the accuracy of the records, leading to higher possibility of human error or bias during the data collection phase. Considering the large number of participants and sample size, this issue is less probable but the data should still be analysed bearing this limitation in consideration.

Additionally, the results obtained in this research highlighted some public health queries. According to the latest registration report published by the General Dental Council in September 2017 (GDC, 2017), the total number of registered practicing dentists was 41,631, of which only 287 were registered specialists in endodontics, which forms 0.69% of the workforce, equating to a ratio of 1:145 endodontist for every registered dentist. In comparison to the United States, there are

195,722 registered dentists with just over 4000 endodontists equating to a ratio of 1:48 (AAE, 2016). This shortage is further complicated by non-practicing registered endodontists on the GDC specialist list in the UK. It is estimated that around 200 out of the 287 registered specialists are restorative consultants practicing in a hospital setting in other subspecialties and do not provide a direct endodontic service. For the majority of the UK, aside from the service provided by teaching hospitals, there is a large shortage of specialist endodontists to refer to within the NHS (BES, 2015). Privately, the majority of the endodontists are concentrated around the Greater London area with few in the North West of England. Some regions such as the North East of England have severe shortage of any registered and practicing private specialists (GDC, 2017). This may explain the relatively high proportion (6%) of proposed referrals to dentists with special interest (DWSI) or dentists with "practice limited to endodontics" rather than to NHS secondary care or private specialists (5%) in endodontics. Many DWSI are now found in the UK and may indeed be helping to reduce the pressure of the general dental practitioners. However, there are currently no recognised guidelines or methods of quality assurance of the dentists with such titles.

When linking the above demographics of the endodontic work force in the UK to the results obtained from this research, with around 28% of the cases encountered requiring specialist input, it becomes immediately apparent that further research is required to utilise the results obtained here to assess the level of shortage of endodontic specialists within the UK health system, both within the national health service and within the private sector. Further research is also required to identify a more tangible system to recognise those dentists with special interest in the field and the level of endodontic complexity that could be referred to them.

4.5 Conclusion

The results obtained in this study provide a good resource and databank for researchers, public health commissioners and academic institutions to access wide range of information concerning the prevalence and distribution of endodontic complexity. The results obtained in this research indicate a shortage of endodontic specialist service in the UK, especially within the National Health Service. Further research is required to utilise these data to identify the nature of the endodontic work force required within the United Kingdom health system and help shaping it into a more productive network.

CHAPTER 5 : CLINICAL IMPLICATIONS AND FUTURE RESEARCH

5.1 Clinical implications

Following the results of the research presented and discussed in the previous chapters, the created tool can help general dental practitioners identify those cases with higher potential of encountering complexity and higher risk of adverse outcomes more predictably. The digital interface will help save clinical time, be more intuitive and provide more information to clarify the ambiguity of certain complexity factors. This in turn may aid the effectiveness of decision-making in deciding to treat the case or to refer it to an appropriate clinician (specialist or dentist with special interest of an appropriate level of training). Which consequently helps placing patients' best interest first and achieving the best treatment outcome for them

This research helped to produce a more objective definition of the term "uncomplicated" root canal treatment as described by the ESE and ADEE, which will help educational institutes in Europe to tailor their undergraduate educating programmes and standardise the level of training and case selection. This is further discussed in section 5.2.

From a public health point of view, the outcome of the prevalence and distribution of factors affecting the complexity of root canal treatment can help educational institutes, health authorities and commissioning services assess the level of need for basic training, further training and commissioning of specialists and dentists with enhanced skills in root canal treatment within the health system.

Linking the research outcomes to the currently proposed prototypes by the Department of Health schemes, this may also help the commissioning bodies adapt the tool and prevalence findings to reliably identify the level of the treatment in the proposed current for general dentists, dentists with enhanced skills, specialist or hospital consultants.

5.2 DEFINITION OF UNCOMPLICATED ROOT CANAL TREATMENT

One of the aims specified in this research was to derive a more objective definition for the term uncomplicated root canal treatment as described by the ESE and ADEE undergraduate curriculum guidelines for Endodontology. This was achieved through a wide-spread literature review and the process of iterative development and the E-CAT evaluation as described in Chapter 3. Following the findings reported in the previous chapters concerning the factors involved in endodontic complexity, it is not surprising that achieving a precise definition is very challenging. Despite its lengthy and wordy nature, the following definition is regarded as an overly simplified strict definition for uncomplicated non-surgical root canal treatment.

The term "uncomplicated" is defined as those anterior or posterior teeth (not including 3rd molars) requiring NSRCT consistent with the following conditions:

- Straightforward clear diagnosis
- No medical conditions reported, or well controlled medical conditions – (ASA Class I and II)
- Patients with no physical or psychological limitations (including normal mouth opening, good patient's cooperation, no physical limitation on reclining chair)
- No radiographic obstructions (including no structures causing radiographic superimposition, no severe gag reflex, normal palatal vault and floor of mouth levels)
- Simple or no pre-treatment required for dental dam isolation (e.g. supra-gingival caries or simple replacement of restorations)
- Unrestored teeth, or teeth with direct restorations not masking the original crown morphology
- No extra-coronal restoration present, or crown, bridge or onlay present but planned to be removed prior to commencing treatment
- No post or core present
- No or small tooth inclination and rotation (< 10°)

- Teeth with small or no root curvature (< 10°)
- Closed (fully formed) apical morphology (<size 60 k-file)
- Radiographically clearly visible pulp chamber and canal space throughout to the apex
- No known atypical root canal shape (e.g. S or C-shape roots) or pulp stones
- No known developmental abnormality (such as fusion or dens invaginatus, taurodontism or microdontism, or dentinogenesis imperfecta)
- Anterior tooth or lower premolar with single canals, upper premolars ≤2, molars ≤3 canals
- No signs of pathological root resorption
- No signs of periodontal-endodontic involvement
- No history of previous dental trauma
- No previous endodontic treatment, or previously initiated but not obturated endodontic treatment with no known iatrogenic damage
- Single rooted (single canals) teeth sub-optimally obturated with gutta-percha (short or poorly condensed) root fillings

The aforementioned criteria describe those cases which have low risk of encountering technical complication or causing adverse outcome and expected to be competently treated by the newly qualified European dentist. Aside from being time-consuming to go through each one of them, these factors still over simplify the classification process and therefore may lead to an overly cautious approach to case selection for undergraduate students. On the other hand, as described in chapter 3 and agreed by the panel of 35 certified endodontists, some factors may carry a low or moderate risk of complexity but may still be suitable to be treated by the newly qualified dentist as long as they are not combined with other factors which may further influence the complexity. When several moderate risk factors accumulate, the overall risk of encountering complexity increases. It is therefore seen more appropriate and time-efficient to utilise the programming built in the E-CAT to

identify those cases classed as “uncomplicated”, rather than simply having cases which “tick” the above mentioned criteria.

5.3 Future research

In order to further investigate the clinical significance of the E-CAT, further research is required to evaluate the clinical relevance of the tool in identifying complex endodontic cases in a clinical setting.

Due to the subjectivity and the large number of variation of the complexity topic, it would be difficult to fully assess the sensitivity of the tool in clinical scenarios. One way of approaching this would be to roll out the tool in an undergraduate setting and prospectively assess the risk of adverse outcome prior to the use of the tool and then assess the outcome of the treatment immediately post operatively and with a specified follow-up period (e.g. 6-12 months). It would also be possible to conduct qualitative research to assess the user experience of the tool and aim to further improve it. This type of research can help further validate the clinical relevance of the "uncomplicated" cases as defined by this research for undergraduate students across the UK and European educational institutes.

Further research is also suggested to develop utilities that reflect how GDPs, public health commissioners and educational establishment would use the E-CAT and focus future research into attaining the highest utility value of the tool.

The above approach can also be rolled out in general dental practice and potentially post-graduate students or specialists to assess the clinical relevance of the tool there both in the UK and across Europe.

Another approach could involve a large retrospective cohort in primary or secondary clinical setting to assess the cases pre-operative clinical data and radiograph using the tool, and then relate it to the postoperative technical and clinical outcomes.

Alternative possibility to assess the sensitivity of the assessment tools can involve an *in vitro* design to involve the utilisation of 3D-printing to standardise a set number of samples being treated by a

large panel of different clinicians and determining an overall average. However, the limitation of this would be standardising the clinicians experience and the simulated environment not necessarily mirroring the clinical settings.

The research also identified a large number of variations when attempting to evaluate root curvature and radiographic canal visibility. Further research for the production of more accurate tools and techniques to help achieving more reproducible results is seen beneficial to improve pre-treatment assessments.

In order to improve the accuracy of the assessment results of the E-CAT, identifying a more methodological approach to develop a calibration method through face to face sessional training or online tutorials, or indeed a combination of both, will be beneficial. Improving the calibration process is thought to provide more accurate assessment results overall.

In the United Kingdom, assessment or treatment need tools such IOTN were successfully incorporated into public health domains. Whether the E-CAT can be used in similar manner is a question that requires further research to address its clinical relevance and any modification that may be required prior to that transformation.

This research did not look into the distinction between the levels of competence or qualifications required to confidently manage moderately and highly complicated cases. Further research can help produce a more evidence based guide on the degree of competence and training required to tackle the different classes of complexities assessed.

The outcomes of the prevalence study indicated a shortage of the endodontic specialist service in the UK, especially within the National Health Service. Further research is required to utilise these data to identify the nature of the endodontic work force required within the United Kingdom health system and help shaping it into a more efficient and productive system.

The results of the second study also identified trends for more complex cases exhibiting higher probability of being extracted. The reasons behind those trends can be due to numerous reasons including patients' wishes, shortage of referral service, financial limitations, and clinicians perceived long term outcome or various other factors. Further research is required to explore this topic.

Finally, as a lateral finding, the results indicated higher tendency of general dental practitioners wishing to keep extra-coronal restoration (crowns, bridges and onlays) *in situ* prior to commencing root canal treatments. Despite some literature favouring the removal of crowns, more clinical research would be beneficial to identify the clinical risks and benefit and long term outcomes of each school of thought.

5.4 Conclusion

The development of E-CAT provided a more credible, more efficient and more reliable platform to assess the complexity of NSRCT compared to currently existing paper-format tools. The literature review and iterative development of the factors influencing endodontic complexity allowed the production of a more objective definition to describe “uncomplicated” root canal treatment as referred to by the ESE and ADEE guidelines.

The outcome of the prevalence study provided a good resource and databank for researchers, public health commissioners and academic institutions to access wide range of information concerning the prevalence and distribution of endodontic complexity. The results obtained in this research indicate a possible shortage within the endodontic specialist service in the UK, especially within the National Health Service.

CHAPTER 6 : BIBLIOGRAPHY

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CHAPTER 7 : APPENDICES

7.1 Examples of existing complexity assessment forms

7.1.1 The AAE form

AAE Endodontic Case Difficulty Assessment Form and Guidelines

PATIENT INFORMATION

Name_____

Address_____

City/State/Zip_____

Phone_____

DISPOSITION

Treat in Office: Yes ☐ No ☐

Refer Patient to:

_____

Date:_____

Guidelines for Using the AAE Endodontic Case Difficulty Assessment Form

The AAE designed the Endodontic Case Difficulty Assessment Form for use in endodontic curricula. The Assessment Form makes case selection more efficient, more consistent and easier to document. Dentists may also choose to use the Assessment Form to help with referral decision making and record keeping.

Conditions listed in this form should be considered potential risk factors that may complicate treatment and adversely affect the outcome. Levels of difficulty are sets of conditions that may not be controllable by the dentist. Risk factors can influence the ability to provide care at a consistently predictable level and impact the appropriate provision of care and quality assurance.

The Assessment Form enables a practitioner to assign a level of difficulty to a particular case.

LEVELS OF DIFFICULTY

MINIMAL DIFFICULTY	Preoperative condition indicates routine complexity (uncomplicated). These types of cases would exhibit only those factors listed in the MINIMAL DIFFICULTY category. Achieving a predictable treatment outcome should be attainable by a competent practitioner with limited experience.
MODERATE DIFFICULTY	Preoperative condition is complicated, exhibiting one or more patient or treatment factors listed in the MODERATE DIFFICULTY category. Achieving a predictable treatment outcome will be challenging for a competent, experienced practitioner.
HIGH DIFFICULTY	Preoperative condition is exceptionally complicated, exhibiting several factors listed in the MODERATE DIFFICULTY category or at least one in the HIGH DIFFICULTY category. Achieving a predictable treatment outcome will be challenging for even the most experienced practitioner with an extensive history of favorable outcomes.

Review your assessment of each case to determine the level of difficulty. If the level of difficulty exceeds your experience and comfort, you might consider referral to an endodontist.

AAE Endodontic Case Difficulty Assessment Form

Criteria and Subcriteria	Minimal Difficulty	Moderate Difficulty	High Difficulty
A. PATIENT CONSIDERATIONS			
Medical history	☐ No medical problem (ASA Class 1*)	☐ One or more medical problems (ASA Class 2*)	☐ Complex medical history/serious illness/disability (ASA Classes 3-5*)
Anesthesia	☐ No history of anesthesia problems	☐ Vasoconstrictor intolerance	☐ Difficulty achieving anesthesia
Patient disposition	☐ Cooperative and compliant	☐ Anxious but cooperative	☐ Uncooperative
Ability to open mouth	☐ No limitation	☐ Slight limitation in opening	☐ Significant limitation in opening
Gag reflex	☐ None	☐ Gags occasionally with radiographs/treatment	☐ Extreme gag reflex which has compromised past dental care
Emergency condition	☐ Minimum pain or swelling	☐ Moderate pain or swelling	☐ Severe pain or swelling
B. DIAGNOSTIC AND TREATMENT CONSIDERATIONS			
Diagnosis	☐ Signs and symptoms consistent with recognized pulpal and periapical conditions	☐ Extensive differential diagnosis of usual signs and symptoms required	☐ Confusing and complex signs and symptoms: difficult diagnosis ☐ History of chronic oral/facial pain
Radiographic difficulties	☐ Minimal difficulty obtaining/interpreting radiographs	☐ Moderate difficulty obtaining/interpreting radiographs (*e.g.*, high floor of mouth, narrow or low palatal vault, presence of tori)	☐ Extreme difficulty obtaining/interpreting radiographs (*e.g.*, superimposed anatomical structures)
Position in the arch	☐ Anterior/premolar ☐ Slight inclination (<10°) ☐ Slight rotation (<10°)	☐ 1st molar ☐ Moderate inclination (10-30°) ☐ Moderate rotation (10-30°)	☐ 2nd or 3rd molar ☐ Extreme inclination (>30°) ☐ Extreme rotation (>30°)
Tooth isolation	☐ Routine rubber dam placement	☐ Simple pretreatment modification required for rubber dam isolation	☐ Extensive pretreatment modification required for rubber dam isolation
Crown morphology	☐ Normal original crown morphology	☐ Full coverage restoration ☐ Porcelain restoration ☐ Bridge abutment ☐ Moderate deviation from normal tooth/root form (*e.g.*, taurodontism, microdens) ☐ Teeth with extensive coronal destruction	☐ Restoration does not reflect original anatomy/alignment ☐ Significant deviation from normal tooth/root form (*e.g.*, fusion, dens in dente)
Canal and root morphology	☐ Slight or no curvature (<10°) ☐ Closed apex (<1 mm in diameter)	☐ Moderate curvature (10-30°) ☐ Crown axis differs moderately from root axis. Apical opening 1-1.5 mm in diameter	☐ Extreme curvature (>30°) or S-shaped curve ☐ Mandibular premolar or anterior with 2 roots ☐ Maxillary premolar with 3 roots ☐ Canal divides in the middle or apical third ☐ Very long tooth (>25 mm) ☐ Open apex (>1.5 mm in diameter)
Radiographic appearance of canal(s)	☐ Canal(s) visible and not reduced in size	☐ Canal(s) and chamber visible but reduced in size ☐ Pulp stones	☐ Indistinct canal path ☐ Canal(s) not visible
Resorption	☐ No resorption evident	☐ Minimal apical resorption	☐ Extensive apical resorption ☐ Internal resorption ☐ External resorption
C. ADDITIONAL CONSIDERATIONS			
Trauma history	☐ Uncomplicated crown fracture of mature or immature teeth	☐ Complicated crown fracture of mature teeth ☐ Subluxation	☐ Complicated crown fracture of immature teeth ☐ Horizontal root fracture ☐ Alveolar fracture ☐ Intrusive, extrusive or lateral luxation ☐ Avulsion
Endodontic treatment history	☐ No previous treatment	☐ Previous access without complications	☐ Previous access with complications (*e.g.*, perforation, non-negotiated canal, ledge, separated instrument) ☐ Previous surgical or nonsurgical endodontic treatment completed
Periodontal-endodontic condition	☐ None or mild periodontal disease	☐ Concurrent moderate periodontal disease	☐ Concurrent severe periodontal disease ☐ Cracked teeth with periodontal complications ☐ Combined endodontic/periodontic lesion ☐ Root amputation prior to endodontic treatment

*American Society of Anesthesiologists (ASA) Classification System

7.1.2 The Dutch DETI and ETC

DETI ("Dutch Endodontic Treatment Index")

yes

- ○ Medical problems (ASA score ≥ 2)
- ○ Physical limitations/ cooperation of patient limited to poor
- ○ Difficult diagnosis
- ○ Premolar >2 canals
- ○ Molar >3 canals/ third molar
- ○ Canal subdivision in middle/ apical third
- ○ Moderate to extreme rotation and/or inclination of tooth (> 10°)
- ○ Aberrant crown and/or root morphology/ very long tooth ≥ 30 mm
- ○ Pretreatment required for isolation with rubber dam
- ○ Crown, core and/or post present
- ○ Moderate to extreme canal curvatures (> 10°)
- ○ Obstructions, resorption, calcification, perforation and/or open apices
- ○ Retreatment
- ○ Endodontic-periodontal lesion
- ○ History of trauma

None of the abovementioned criteria is applicable → DETI score A → Initiate root canal treatment

One or more of the abovementioned criteria is applicable → DETI score B → Assess grade of difficulty with the Treatment Classification form

CASE CLASSIFICATION ACCORDING TO THE DEGREES OF DIFFICULTY AND RISK

Criteria and Subcriteria	Average Risk (1 unit / item)	High Risk (2 units / item)	Very High Risk (5 units / item)
A. PATIENT CONSIDERATIONS			
1. Medical history/ anaesthesia / patient management	☐ No medical problem (ASA Class I)	☐ Special attention: pacemaker / antibiotic allergy (ASA Class II) ☐ Vasoconstrictor intolerance ☐ Lack of cooperation / fear	☐ Complex medical history/ serious illness / disability (ASA Classes III and IV*) ☐ Intolerance to anaesthesia ☐ Resistance to anaesthesia
2. Diagnosis	☐ Signs and symptoms straight forward: clear diagnosis	☐ Differential diagnosis of usual signs and symptoms	☐ Confusing and complex signs and symptoms: difficult diagnosis ☐ Indeterminable diagnosis
3. Mouth aperture and physical limitations	☐ Normal mouth aperture (35mm+)	☐ Reduced aperture (25-35mm) ☐ Difficulty holding film	☐ Non-functional aperture (-25mm) ☐ Limited reclination
4. Radiographic difficulties	☐ Average conditions	☐ Gagging ☐ High floor (lower premolars and canines) ☐ Narrow or low palatal vault	☐ Hard to solve superimposed anatomical structures
B. TOOTH CONSIDERATIONS			
5. Position in the arch and inclination	☐ Anterior or premolar ☐ Small inclination (-10°) ☐ Small rotation (-10°)	☐ 1st or 2nd molar ☐ Moderate inclination (10-30°) ☐ Moderate rotation (10-30°)	☐ 3rd molar ☐ Extreme inclination (+30°) ☐ Extreme rotation (+30°)
6. Tooth isolation and access / morphologic aberrations of crown	☐ Normal original crown morphology or one usable as is ☐ No pretreatment required for isolation ☐ Stable clamp	☐ Taurodontism / microdens ☐ Simple pretreatment required for isolation ☐ Unstable clamp (no retention)	☐ Fusion / dens in dente* ☐ Extensive pretreatment required for isolation ☐ Impaired access (post / core / broken instrument /amalgam…) ☐ Porcelain / gold occlusal restoration or crown / splint ☐ Clamp almost impossible to place
7. Canal and root shapes	☐ Canal path into *I* form ☐ Small or no angle (-10°) in the canal ☐ Single canal anterior or premolar ☐ Closed apex	☐ Canal path into *J* form ☐ Moderate angle (10-30°) ☐ Molar with 3 canals or less ☐ Premolar or anterior with 2 canals ☐ Previously initiated endodontic treatment ☐ Crown axis different from root axis ☐ Canal > 25 mm long	☐ Canal path into *C* or *S* form ☐ Extreme angle (+30°) ☐ Molar with 4 canals or more ☐ Premolar with 3 canals ☐ Canal subdivision in the apical or middle thirds ☐ C-shape canal system ☐ Internal canal wall of a curve < 2 mm thick, on X-Ray films ☐ Open apex
8. Canal calcifications	☐ Wide and clear canal	☐ Canal and chamber are visible but quite reduced ☐ Pulp stones	☐ Almost undistinctive canal path in part or throughout ☐ Canal no longer visible*
9. Resorptions		☐ Internal resorption (without perforation) ☐ Apical resorption	☐ Internal resorption with perforation* ☐ External resorption with* or without perforation
10. Mechanical perforation		☐ Supra-osseous root perforation	☐ Sub-osseous root perforation*
C. ADDITIONAL FACTORS			
11. Trauma history	☐ Uncomplicated crown fracture of mature or immature teeth ☐ Radicular fracture in apical third ☐ History of concussion	☐ Complicated crown fracture of mature teeth ☐ Radicular fracture in middle third ☐ History of subluxation / alveolar fracture	☐ Complicated crown fracture of immature teeth ☐ Radicular fracture in cervical third ☐ Other luxations / avulsion
12. Retreatment			☐ Retreatment
13. Periodontal - endodontic condition			☐ Mobility / pocket / fenestration / dehiscence ☐ Furcation involvement ☐ Root resection / hemi-section (expected or done)

*** ASA Class IV, fusion / dens in dente, invisible canal, sub-osseous / resorptive perforation belong to Class 3 automatically.**

Results:

Total _____

15 to 17 units:	**Class 1**
18 to 25 units:	**Class 2**
More than 25 units:	**Class 3**

Disposition:

☐ **Accepted** or ☐ **Referred**

7.1.3 The Restorative Index Of Treatment Need form

Fig. 4 — **Component 2: root canal treatment assessment**

Root canal treatment assessment (permanent teeth)
Conventional root canal treatment or retreatment is the clinical procedure of choice. Surgical treatment should only be considered when conventional treatment is inappropriate.

• Single/multiple root canals with curvature < 15° to root axis that are considered negotiable from radiographic or clinical evidence through their entire length. No root canal obstruction or damaged access • Surgical treatment – Single root canals – Radiolucency < 6 mm diameter	=Complexity 1
• Single/multiple root canals with curvature > 15° but < 40° to root axis that are considered negotiable from radiographic or clinical evidence through their entire length. • Surgical treatment – Single root canals – No evidence of radiolucency – Hemisection of mandibular molars • Teeth with incomplete root development	=Complexity 2
• Single/multiple root canals with curvature > 40° • Single/multiple root canals that are *not* considered negotiable from radiographic or clinical evidence through their entire length • Surgical treatment – Multi rooted teeth – Single root canals – Radiolucency > 6 mm diameter • Teeth with iatrogenic damage or pathological resorption • Teeth with difficult root morphology	=Complexity 3

15° to the root axis

40° to the root axis

7.2 Letter of invitation to general dental practitioners

Dear Colleagues,

We are currently working on developing a new digital tool to assess the difficulty of root canal treatments in a form of an online tool which combines the available tools in the literature in a simple intuitive app. The tool will use the data input to help classifying the Endodontic case in one of the 3 difficulties, uncomplicated, moderately complicated and highly complicated.

We are inviting all GDPs interested in trialling this new app and helping in the prevalence survey across the country to take part. We are asking those who are interested to assess 10-15 random cases where endodontic treatment was offered as a "treatment option" consecutively. Using the tool all the responses will be anonymised, no patient data is required or included. Each case should not take more than few minutes to complete; some will take less than a minute.

The tool simply aims to provide a quick and easy way to assess how difficult an endodontic treatment is predicted to be. For example, "red" outcome would indicate high case complexity and recommend treatment by a specialist.

We are inviting collaboration of dentists working in general practice to feedback on this tool and help researching the "prevalence" of complex and difficult endodontic treatments in general dental practice. It is currently difficult to assess how many endodontists or dentists with enhanced skills are required within the health system, as we do not have figures of how common or uncommon complex endodontic cases are in general practice in the UK. Assessing the prevalence may help the commissioning bodies have an idea of how many endodontic referral centres are required per dentist within your local area for referral services.

If you are interested in taking part or have any further queries, please feel free to email us on o.essam@liv.ac.uk and we will contact you back to explain the process further. Your valuable time and thoughts on this will be highly appreciated.

Looking forwards to hearing from you.

Best wishes

Obyda Essam

Speciality Registrar in Endodontics

Liverpool University Dental Hospital

7.3 Participant information leaflet

The Royal Liverpool and Broadgreen University Hospitals NHS Trust

PARTICPANT INFORMATION SHEET

Name of the Study

Endodontic Case Assessment Tool, a new online tool to assess endodontic complexity and prevalence.

Introduction

The need for endodontic treatment in dental care is an established and well attested fact in the literature. A substantial perceived need for referring endodontic cases to endodontic specialists has been reported. In order to improve the success rate for endodontic treatment by general dental practitioners (GDPs), the referral of difficult cases to an experienced endodontist should be made possible to the treating dentists in the best interest of the patient and most predictable treatment outcome. In order to be able to refer difficult endodontic cases appropriately, two requirements need to be satisfied. First, GDPs need to be able to **predictably** identify cases with higher difficulties and treat or refer to the appropriate practitioner. Secondly there needs to be sufficient number of endodontic specialists or dentists with further advanced skills in endodontics to refer to. The aims of this project is to determine the prevalence of complex root canal treatment cases in general practice to help to assess the level of need for endodontic training within the health system.

Methods

We are asking participating dentists to assess 10-15 random **consecutive** cases where endodontic treatment was offered as a "treatment option". Using the tool all the responses will be anonymised, no patient data is required or included. Each case should not take more than few minutes to complete; some may take less than a minute.

The link to the tool is as follows:
www.e-cat.uk

Prior to starting the research, we would like you to familiarise yourself with the tool. We are asking you to randomly pick few endodontic cases you have recently treated and use the tool to assess them. These will not be recorded on the research data to start with.

When the research officially starts, you will need to keep a record of all the cases where you have offered the patient root canal treatment as a treatment option. To eliminate selection **bias**, those cases should start on an agreed date and must be **consecutive** with no cases being missed once the recording starts. Ideally the cases should be assessed at the "examination", "treatment plan" or "emergency" appointment.
To eliminate other confounding factors, we are asking for all cases where RCT endodontic treatment is indicated to be included regardless of whether the patient chooses to go ahead with the treatment or not. Cases where the patient chooses to extract the tooth instead or defer the treatment for personal or financial reasons (e.g. cannot afford treatment or referral) **should still be included**. Cases where pulp extirpation was done or the case was referred to secondary care or private specialist should also be included.

The following steps aim to briefly explain the methodology protocol

- Please head to the website www.e-cat.uk
  This can be accessed from your computer, tablet or smart phone. However, a computer or laptop is the preferred choice.

- Click on Begin
- The first page will show you a series of "screening" 12 questions.
- *For first time users, you probably would want to read them a couple of times to familiarise yourself with the outline. Once you know them, it will not take much time to simply answer Yes/No. The default answer is set for "No" unless changed.*

- It is important you answer yes to all the relevant questions as this will determine what questions are relevant to that case on the following page. *In order to change the answer to "YES", simply click on the "no" once*

- On the second page, please read the question and click/tick the relevant answer. For some questions, you may have more than one choice to select.

- If you are unsure of any question, please feel free to drop me an email to enquire or ask any question.

- Click "Finish Assessment"

- It will then ask you whether the case is for personal **"Assess case only"** or it is a case you would like to **"Assess and record"** on the endodontic research.
- Assessment only option will show you the difficulty class expected for that case but will not record it on our research.
- If the case is to be added to the research please select record then enter your PIN code. To eliminate bias, the programme will not tell you the difficulty of that case.

Once you have completed 10-15 cases, you are welcome to keep using the tool or record more cases – but only do so if they have been in consecutive random order. The more data we collect, the more information we have to feedback into the accuracy of the research.

Could you please email me when you have completed your cases and whether you intend to keep recording more cases. The **certificate of participating in research** will state your valuable input and the number of cases you have helped inputting if you wish for us to specify.

Purpose of study

The tool simply aims to provide a quick and easy way to assess how difficult an endodontic treatment is predicted to be. For example, "three" outcome would indicate high case complexity and recommend treatment by a specialist or more experience practitioner.

This will help researching the "prevalence" of complex and difficult endodontic treatments in general dental practice. It is currently difficult to assess how many endodontists or dentists with enhanced skills are required within the health system, as we do not have figures of how common or uncommon complex endodontic cases are in general practice in the UK.

Assessing the prevalence may help the commissioning bodies have an idea of how many endodontic referral centres are required per dentist within your local area for referral services.

Confidentiality

This study will not include any dentist or patient personal information. The survey information will be stored on a password encrypted database. The data will be reviewed in a secured environment by researchers at The University of Liverpool as part of doctorate degree research by a restorative consultant and speciality registrar in Endodontics.

What Happens next

In order to ensure the accuracy of this national research, we are going to need your commitment to record the cases as accurately as possible. Whenever you have any questions about anything please feel free to contact us as shown below.

Once you have had time to familiarise yourself with the tool, could you please email me back confirming your enrolment in the study. We will require your **full name**, your **GDC number** (for CPD purposes), **your practice address and whether you are predominantly NHS or private practice**. Where possible, we will need a confirmation of your practice management's permission to participate in this research. Once we have those, we will provide you with a personal **PIN** code to match your details in order to start recording the cases.
We hope that you see this as exciting opportunity to have further insight of the future of endodontic treatments in the UK or improve your personal CV with some research involvement.

Contact

If there are any issues with the use of this tool, please do not hesitate to contact me on the following email address or contact detail:

Obyda Essam
Liverpool University Dental Hospital
Pembroke Place, Liverpool
o.essam@liv.ac.uk
Third Floor
Tel: 0151 780 5240
Mobile: 07725545853

Your valuable time and thoughts on this will be highly appreciated.

Best wishes

Obyda Essam
Teaching fellow in Endodontology
Speciality Registrar at Liverpool University Dental Hospital

7.4 Trust Sponsorship Letters

The Royal Liverpool and Broadgreen University Hospitals NHS Trust

Royal Liverpool University Hospital
Prescot Street
Liverpool
L7 8XP

Tel: 0151 706 2000
Fax: 0151 706 5806

TRUST INTENTION TO SPONSOR LETTER

Dr Liam Boyle
Royal Liverpool Hospital
Dental Hospital
Pembroke Place
Liverpool
L7 8XP

Date: **14/09/2015**

Dear Dr Boyle

RD&I No: 5102
Assessing Difficulty and Prevalance of Complex Endodontic Treatments

I can confirm that the Royal Liverpool and Broadgreen University Hospitals NHS Trust, will, in principle, be willing to act as Sponsor for the above research project under the Department of Health's Research Governance Framework 2nd Ed 2005.

The project is currently being reviewed through the necessary sponsorship approval procedure. Before you can commence recruitment to your study, you will need full sponsorship and Trust Approval.

The RLBUHT sponsorship committee reserves the right to withdraw sponsorship at any stage should any significant change be made to the application as per SOP004 available on the Trust intranet.

This letter authorises you to now proceed to submission of your ethics application and/or regulatory submissions as appropriate.

Yours sincerely

Prof T Walley
Research Governance Chair

7.5 Ethical Approval Letter

NHS
Health Research Authority
NRES Committee North East - Newcastle & North Tyneside 1
Jarrow Business Centre
Jarrow REC Centre
Room 001
Rolling Mill Road
Jarrow
NE32 3DT

Telephone: 0191 428 3565

30 October 2015

Dr Liam Boyle
Restorative Consultant/
Senior Lecturer
Liverpool University Dental Hospital
Pembroke Place
Liverpool
L3 5PS

Dear Dr Boyle

Study title:	**Development of new computerised tool for assessing the difficulty and prevalence of complex endodontic treatments**
REC reference:	**15/NE/0372**
IRAS project ID:	**181673**

The Proportionate Review Sub-committee of the North East - Newcastle & North Tyneside 1 Research Ethics Committee reviewed the above application by correspondence.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this favourable opinion letter. The expectation is that this information will be published for all studies that receive an ethical opinion but should you wish to provide a substitute contact point, wish to make a request to defer, or require further information, please contact the REC Manager Ms Gillian Mayer, nrescommittee.northeast-newcastleandnorthtyneside1@nhs.net. Under very limited circumstances (e.g. for student research which has received an unfavourable opinion), it may be possible to grant an exemption to the publication of the study.

Ethical opinion

On behalf of the Committee, the sub-committee gave a **Favourable** ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

The PR Sub-Committee agreed that this was a well presented study with no material ethical issues.

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission ("R&D approval") should be sought from all NHS organisations involved in the study in accordance with NHS research governance arrangements. Guidance on applying for NHS permission for research is available in the Integrated Research Application System or at http://www.rdforum.nhs.uk.

Where a NHS organisation's role in the study is limited to identifying and referring potential participants to research sites ("participant identification centre"), guidance should be sought from the R&D office on the information it requires to give permission for this activity.

For non-NHS sites, site management permission should be obtained in accordance with the procedures of the relevant host organisation.

Sponsors are not required to notify the Committee of approvals from host organisations.

Registration of Clinical Trials

All clinical trials (defined as the first four categories on the IRAS filter page) must be registered on a publically accessible database. This should be before the first participant is recruited but no later than 6 weeks after recruitment of the first participant.

There is no requirement to separately notify the REC but you should do so at the earliest opportunity e.g. when submitting an amendment. We will audit the registration details as part of the annual progress reporting process.

To ensure transparency in research, we strongly recommend that all research is registered but for non-clinical trials this is not currently mandatory.

If a sponsor wishes to request a deferral for study registration within the required timeframe, they should contact hra.studyregistration@nhs.net. The expectation is that all clinical trials will be registered, however, in exceptional circumstances non registration may be permissible with prior agreement from the HRA. Guidance on where to register is provided on the HRA website.

It is the responsibility of the sponsor to ensure that all the conditions are complied with before the start of the study or its initiation at a particular site (as applicable).

Ethical review of research sites

The favourable opinion applies to all NHS sites taking part in the study, subject to management permission being obtained from the NHS/HSC R&D office prior to the start of the study (see "Conditions of the favourable opinion").

Approved documents

The documents reviewed and approved were:

Document	*Version*	*Date*
Letter from funder		
Letters of invitation to participant [Letter of invitation]	1.0	01 June 2015
Other [CV for second academic supervisor Fadi Jarad]		

Other [Email noting further information & clarification of sponsor details]		23 October 2015
Participant information sheet (PIS)	1.0	23 October 2015
REC Application Form [REC_Form_21102015]		21 October 2015
Research protocol or project proposal [Full Research Protocol]	2.0	19 October 2015
Summary CV for Chief Investigator (CI) [CV]		21 October 2015
Summary CV for student investigator [Obyda Essam]		23 October 2015
Validated questionnaire [Questionnaire Table]	1	05 May 2015

Membership of the Proportionate Review Sub-Committee

The members of the Sub-Committee who took part in the review are listed on the attached sheet.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Reporting requirements

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

The HRA website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

User Feedback

The Health Research Authority is continually striving to provide a high quality service to all applicants and sponsors. You are invited to give your view of the service you have received and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website: http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance/

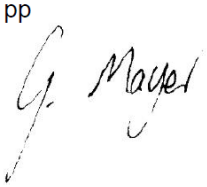
HRA Training

We are pleased to welcome researchers and R&D staff at our training days – see details at http://www.hra.nhs.uk/hra-training/

With the Committee's best wishes for the success of this project.

15/NE/0372	Please quote this number on all correspondence

Yours sincerely
pp



Professor Philip Preshaw
Chair

Email: nrescommittee.northeast-newcastleandnorthtyneside1@nhs.net

Enclosures:	*List of names and professions of members who took part in the review*
	'After ethical review – guidance for researchers'
Copy to:	Mrs Heather Rogers – Research Governance, Royal Liverpool & Broadgreen University Hospitals NHS Trust
	Mr Obyda Essam - Honorary Speciality Registrar in Endodontics & DDsc Student

North East - Newcastle & North Tyneside 1 Research Ethics Committee

Attendance at PRS Sub-Committee of the REC meeting by correspondence

Committee Members:

Name	*Profession*	*Present*	*Notes*
Professor Philip Preshaw (Chair)	Professor of Periodontology & Consultant in Restorative Dentistry	Yes	
Dr Mike Bone (Vice Chair)	Consultant Physician	Yes	
Reverend Nigel Goodfellow	Head of Chaplaincy	Yes	

Also in attendance:

Name	*Position (or reason for attending)*
Ms Gillian Mayer	REC Manager

7.6 European Society of Endodontology Educator Grant

European Society of Endodontology

Young Educator Grant 2016

The European Society of Endodontology (ESE) awards a young educator grant.

Award 4,400 Euros to Obyda Essam

Project: Development of new digital Endodontic Case Assessment Tool.

Endodontic treatments can vary significantly in their complexity, some cases can be uncomplicated and require relatively basic core skills and experience to achieve a predictable outcome; other cases may require a longer clinical time and command more advanced technical skills and expertise. There is always a legal and ethical obligation when determining the difficulty of any form of dental treatment, in order to ensure the treatment is carried out in the best interests of the patient by a suitably competent clinician. The Association for Dental Education in Europe (ADEE) and the European Society of Endodontology (ESE) undergraduate competency guidelines refer to the graduating European dentist as being competent in the management of 'uncomplicated' anterior and posterior teeth, yet neither clearly defines what is meant by uncomplicated.

Several paper-based assessment forms exist, including the American Association of Endodontists (AAE), the Dutch Endodontic Treatment Index and the England RCS restorative treatment index have been used for similar purposes. However, little research has been undertaken to assess the validity and reliability of these tools. Despite their benefits, they are found to be relatively time consuming and less user-friendly. The current study incorporates elements of existing case assessment forms into a more intuitive evidence based assessment tool. Similar to the ITI implants "SAC" tools, a new digital Endodontic Case Assessment Tool (named E-CAT) is being developed as part of a doctorate research the University of Liverpool to classify endodontic treatments. Dental educators and professional will be able to use the E-CAT to define different level of complexities into one of the following categories:

1 - Uncomplicated, low risk of adverse outcome - treatment to be carried out by recent dental graduates or dentists without further enhanced experience in endodontics.

2- Moderately complicated, moderate risk of adverse outcome; treatment to be provided by experienced dentists or practitioners who have had further non-specialist training.

3- Highly complicated, high risk of adverse outcome; treatment to be provided by recognised specialists in Endodontics.

An aim of this research is therefore to develop and maintain a tool to reliably define the different levels of complexity of endodontic cases for educational and professional use. This ultimately can define that 'uncomplicated' category in the ADEE and ESE guidelines and help provide a baseline level of competence as reference point.

Obyda Essam

Obyda qualified from Newcastle University, United Kingdom, with a Bachelor of Dental Surgery (BDS) and completed further foundation training at the Dental Northern Deanery, North East England. He then practiced in a number of general dental practices in the North West when he decided undertake the Membership of the Joint Dental Faculty at the Royal College of Surgeons in London (MJDF RCS Eng) in 2012.

Obyda later joined the University of Liverpool as a teaching fellow in Endodontology and commenced a 3 year full-time speciality training post and clinical professional doctorate degree in Endodontics (DDSc Endodontics) in 2014. He is currently an honorary Specialty Registrar in Endodontics at Higher Education North West HENW. Obyda's ongoing research focuses on accurate assessment of endodontic cases complexity and assessing the prevalence of complex endodontic cases in the general dental practice in the UK. Alongside his clinical practice, He is actively involved in teaching and training undergraduate dental students at Liverpool. In addition to attending national and international conferences, Obyda is a member of the British Dental Association, British Endodontic Society and the European Society of Endodontology.

7.7 Invitation letter to endodontic specialists

Dear (Colleague Name),

I hope this finds you well and you do not mind me approaching you with this email. I would be very grateful for your valuable input on a new endodontic case assessment tool.

I am a clinical lecturer and honorary registrar in Endodontics at the Liverpool University Dental Hospital. Alongside Dr Liam Boyle and Dr Fadi Jarad (Restorative consultants at LUDH), we are conducting a national Endodontic study investigating new complexity assessment tool and determining prevalence of complex Endodontic cases in practice.

Similar to the orthodontic IOTN and implants ITI SAC tools, a new online Endodontic Case Assessment Tool (named E-CAT) has been developed at Liverpool University Dental Hospital to classify Endodontic treatments. The tool incorporates existing AAE, Dutch and the RCS treatment assessment forms into a more intuitive evidence based approach. The aim is to produce a tool to reliably define different level of complexity of endodontic cases for educational purposes, and to aid GDPs to predictably assess the complexity of endodontic treatment in general dental practice, both NHS and private. The app provided good results on trial but we now need to validate it. A number of GDPs and specialists helped recently to internally validate this tool.

The objective now is to get "experts opinion" in Endodontics (Restorative consultants with interest in Endodontics and GDC registered Endodontist Specialists) to give us their own opinion on the complexity of 15 clinical endodontic cases. The purpose of the external validation is to correlate GDPs assessment to Endodontic expert and check whether they can use the tool to arrive to the same or similar assessment. I fully appreciate the busy nature of your schedule. Your help will be greatly appreciated by the team at Liverpool and the dental community. All that is required is your own assessment of the attached 15 cases. I would expect each case to take 1-2 minutes so we are estimating 15-20 mins for the exercise.

Based on the radiographs attached and the clinical information, we would appreciate if you could assess those cases using the judgment of your own clinical experience and grade them on your opinion according to what you expect the complexity of the endodontic treatment would be if you were to treat it or allocate it; 1, 2 or 3.

1 - Uncomplicated, low risk - treatment to be carried out by recent dental graduates or GDPs without further enhanced experience in endodontics.

2- Moderately complicated, moderate risk of adverse outcome; treatment to be provided by experienced GDPs or practitioners who have had further non-specialist training.

3- Highly complicated, high risk of adverse outcome; treatment to be provided by recognised specialists in Endodontics

These can be written in a comment box next to each case. All we need is 1, 2 or 3. Once completed if you could attach the comments back reply to this email we would be very grateful.

If you would like to check out the tool yourself, you can find it on www.e-cat.uk. But please note that your comment on the complexity of the cases should come from your own judgment rather than using the tool.

I look forward to hearing from you. Should you have any further queries, comments or feedback on this project please do not hesitate to contact me. Thank you again.

Best Wishes

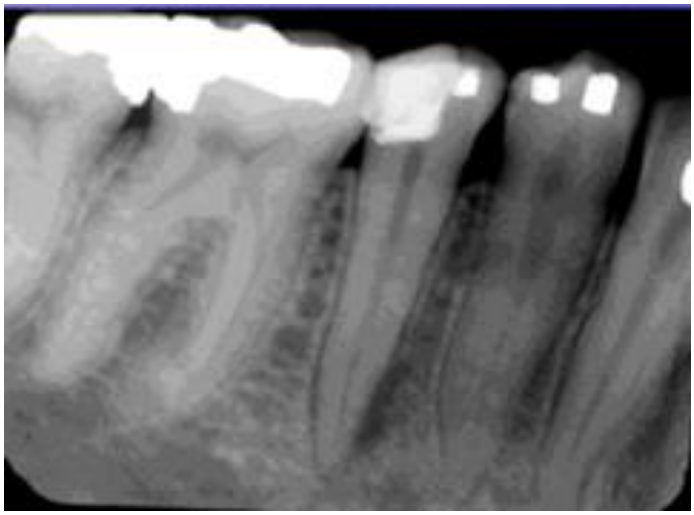
Obie - Teaching Fellow and StR in Endodontics @ LUDH

7.7 Clinical Cases scenarios used in the study

Case 1

- LR5
- Male 28
- Recent deep fill
- No known history of trauma
- No relevant MH
- Normal mouth opening
- EPT and Endofrost – negative
- Straight forward diagnosis: C.A.P

Sinus or Swelling	Yes – tracking to
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	No



- UR1
- Male, 25
- Metal Ceramic Crown – no contra-indication to remove crown
- Sinus
- Failed RCT
- Normal mouth opening
- History of trauma at young age
- Controlled diabetes. ASA II

Sinus or Swelling	Sinus tracking UR1
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Adequate coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	No deficiencies
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	N/A

- UR2
- Male, 52
- **Metal ceramic crown**
- **Root resorption**
- History of trauma at young age
- Clear MH
- Normal mouth opening
- EPT and Endofrost – negative
- Differential diagnosis CAP, internal root resorption with perforation

Sinus or Swelling	Yes
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No

- LR8
- Female, 46
- **Long term IV bisphosphonate**
- **functional tooth – pt wishing for RCT**
- No history of trauma
- Normal mouth opening
- EPT and Endofrost – negative
- Differential diagnosis CAP LR8

Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No

- LR6
- Female 23
- Recurrent caries occlusal
- No known history of trauma
- No relevant MH
- Normal mouth opening
- EPT and Endofrost – negative
- Straight forward diagnosis: C.A.P

Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	No

- UL5
- Male 38
- Already accessed at emergency dentist
- Could not locate canal
- Mild S shape canals
- No known history of trauma
- No relevant MH
- Normal mouth opening
- EPT and Endofrost – negative
- Straight forward diagnosis: C.A.P

Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	No

- LR3
- Female, 32
- Already accessed by GDP – unable to locate canal
- Canal space not invisible but quite reduced
- No known history of trauma
- No relevant MH
- Normal mouth opening
- EPT and Endofrost – negative
- Straight forward diagnosis

Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	No

- LR7
- Male, 38
- Large fill – traumatic exposure by previous dentist
- Abscess one month later – tooth turned non-vital
- Canal space visible but quite reduced
- **Mild 10-20 degree tilted – no rotation.**
- **Moderately reduced mouth opening of around 25-30mm**
- **Moderate 10-30 degree curvature**
- No known history of trauma
- Controlled diabetes and hypertension. ASA II
- EPT and Endofrost – negative on LR7

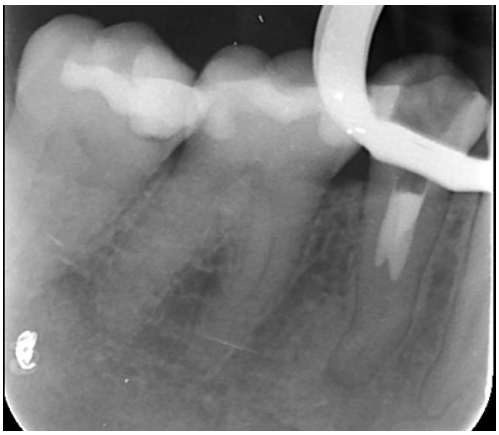
Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Adequate coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	No

- UR5
- Male, 47
- Firmly cemented post
- Metal Ceramic Crown – no contra-indication to remove crown
- 20-30 degree tilt
- Sclerotic apical third
- Failed RCT
- Normal mouth opening
- History of trauma at young age
- Clear MH

Sinus or Swelling	Sinus tracking UR5
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Adequate coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	No
Crown condition	No deficiencies
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	N/A

- LR5
- Female, 35
- **Already accessed by GDP – unable to fill further**
- **Canal space invisible in coronal 2/3 third**
- **10-30 degree root curvature**
- Very sclerotic/indistinctive in apical third
- No known history of trauma
- ASA II MH
- Normal mouth opening
- EPT and Endofrost – negative
- Straight forward diagnosis: C.A.P

Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No



- UR1
- Female, 40
- Chipped tooth at young age.
- No relevant MH
- Normal mouth opening
- EPT and Endofrost – negative
- Straight forward diagnosis: C.A.P

Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	No

- UR4
- Female, 40
- **Large composite restoration**
- **Fractured instrument(s)**
- No history of trauma
- Clear MH
- Normal mouth opening
- EPT and Endofrost – negative
- Differential diagnosis CAP UR4 and failed RCT UR5

Sinus or Swelling	Yes
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No

- UL1
- Male, 10 years old
- **Large composite restoration**
- **Trauma with complicated crown fracture 6/12 ago**
- **Open apex (80+)**
- No history of trauma
- Clear MH
- **Reduced mouth opening (20-25mm)**
- **Nervous child, limited cooperation**
- EPT and Endofrost – negative
- Differential diagnosis CAP UL1

Sinus or Swelling	Yes
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No

- LR6
- Female, 34
- **Referred with perforation (bifurcation)**
- **Previously obturated with GP**
- **Metal Ceramic crown – no contra-indication to remove**
- No history of trauma
- Clear MH
- Normal mouth opening
- EPT and Endofrost – negative
- Differential diagnosis CAP associated with failed RCT LR6

Sinus or Swelling	Yes
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Good coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	N/A
Terminal Tooth, Denture or Bridge abutment	No

- UR4
- Male, 62
- Metal ceramic crown
- Already accessed by GDP through crown – unable to locate canals
- Canal space visible but moderately reduced apically
- No known history of trauma
- ASA II - controlled
- Normal mouth opening
- EPT and Endofrost – negative
- Straight forward diagnosis: irreversible pulpitis and been accessed by GDP
- Tooth tilted

Sinus or Swelling	No
Periodontal condition	Normal physiological pocketing
Restorability Assessment	Adequate coronal tooth tissue
Sensibility Tests	EPT and Endo-Frost – Negative
Tenderness to Percussion	Yes
Crown condition	No leakage
Terminal Tooth, Denture or Bridge abutment	No
Discolouration	No

7.8 Poster presentation at the ESE 18th Biennial ESE Congress - Brussels, Belgium - September 2017.

The complexity of non-surgical endodontic treatment in general dental practice in the UK: a prevalence study

Essam O, Boyle EL, Jarad FD
Department of Restorative Dentistry, School of Dentistry, University of Liverpool, United Kingdom

UNIVERSITY OF LIVERPOOL

Introduction

- For any form of dental treatment, there is always a moral, legal and ethical obligation when determining the complexity of the procedure in order to ensure it lies within the level of competence of the treating clinician.
- In order to improve the success rate for endodontic treatment in general dental practice, the referral of the more complex cases to an experienced endodontist should be made possible for the best interest of the patient and achieving most predictable treatment outcome.
- In order to be able to refer complex endodontic cases appropriately, there needs to be sufficient number of endodontic specialists or dentists with further advanced skills in endodontics to refer to.
- From a public health point of view, there have been no studies conducted to determine the prevalence of complex endodontic cases in general dental practice or the level of complexity and degree of expertise required. This makes it very difficult to estimate the number endodontic specialists necessary within the health system.

Aims

- To assess the prevalence of non-surgical endodontic case complexity in general dental practice.
- To assess the level of need for more advanced endodontic training within the health system.

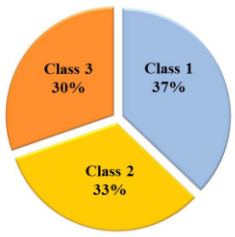
Methodology

- Thirty fully qualified dentists working within general dental practice across the UK were recruited. Each dentist assessed 10-15 consecutive potential endodontic cases as encountered in their day-to-day clinical practice.
- The data was collected using an online Endodontic Complexity Assessment Tool (E-CAT) recently developed at The University of Liverpool. The tool allowed the data to be recorded into a secure database. Information on tooth-related factors, systemic factors, oral diagnosis and patient-related factors was recorded. Three levels of complexity were defined for the analysis; class 1 (uncomplicated), class 2 (moderately complicated) and class 3 (highly complicated).
- The data was analysed to express period prevalence with a 95% confidence interval using SPSS 22 statistical software.

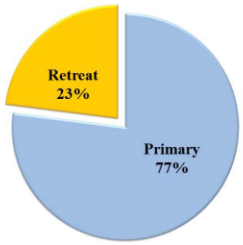
Results

- In total, 421 endodontic cases were evaluated. The distribution of complexity over classes 1, 2 and 3 was 37.1%, 32.6% and 30.3% respectively.
- Root canal retreatments formed 23.1% of the cases encountered. The majority of the cases (66.7%) appeared to have <15 degree root curvature, 29.2% had 15-40 degree curvature and only 4.1% had > 40° curvature.
- Teeth with existing extra-coronal restorations formed 19.8% of the cases encountered.
- Radiographically, visible and moderately reduced canal space was reported in 76.2% of the cases, while 20.5% had severely reduced canal space and only 3.3% were perceived to have invisible canal space.
- History of trauma was encountered in 9.2% of the evaluated cases.

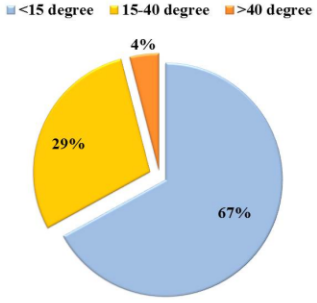
Distribution of Endodontic Complexity



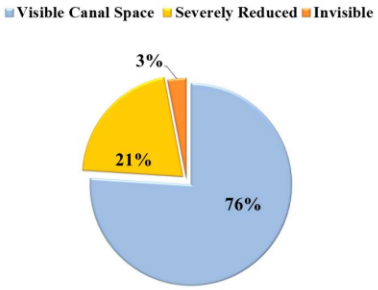
Proportion of Root Canal Retreatment



Distribution of Root Curvature



Distribution of Radiographic Canal Visibility



Conclusions

- Class 3 complexity was least prevalent but relatively comparable distribution across the three level of endodontic treatment complexity was observed.
- The prevalence of severe root curvature and severely reduced canal space was relatively low.
- Previously root filled teeth and teeth with pre-existing extra-coronal restorations formed a considerable proportion of the endodontic treatment encountered in general dental practice.

References

1. DIETZ, G. C., SR. & DIETZ, G. C., JR. 1992. The endodontist and the general dentist. Dent Clin North Am, 36, 459-71
2. MESSER, H. H. 1999. Clinical judgement and decision making in endodontics. Aust Endod J, 25, 124-32
3. REE, M. H., TIMMERMAN, M. F. & WESSELINK, P. R. 2003. Factors influencing referral for specialist endodontic treatment amongst a group of Dutch general practitioners. Int Endod J, 36, 129-34

Acknowledgements

- The development of the E-CAT is partly funded by a research grant awarded by the European Society of Endodontology.
- Favourable ethical approval was granted by the North East research ethics committee. REC reference: 15/NE/0372.

NHS
Health Education England

7.9 Abstract published in the IEJ following poster presentation

The complexity of non-surgical endodontic treatment in general dental practice in the UK: a prevalence study.

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Aim: The aim of the study was to assess the prevalence of non-surgical endodontic case complexity in general dental practice.

Methodology: Thirty fully qualified dentists working within general dental practice across the UK were recruited. Each dentist assessed 10-15 consecutive potential endodontic cases as encountered in their day-to-day clinical practice. The data was collected using an online endodontic case assessment tool (E-CAT) recently developed at The University of Liverpool. The tool allowed the data to be recorded into a secure database. Information on tooth-related factors, systemic factors, oral diagnosis and patient-related factors was recorded. Three levels of complexity were defined for the analysis; class 1 (uncomplicated), class 2 (moderately complicated) and class 3 (highly complicated). The data was analysed to express period prevalence with a 95% confidence interval using SPSS 22 statistical software.

Results: Overall, 385 endodontic cases were evaluated. The distribution of complexity over classes 1, 2 and 3 was observed to be 37.1%, 32.6% and 30.3% respectively. Endodontic retreatments formed 23.1% of the cases encountered. The majority of the cases (66.7%) appeared to have <15 degree root curvature, 29.2% had 15-40 degree curvature and only 4.1% had > 40° curvature. Teeth with existing extra-coronal restorations formed 19.8% of the cases encountered. Radiographically, visible and moderately reduced canal space was reported in 76.2% of the cases, while 20.5% had severely reduced canal space and only 3.3% were perceived to have invisible canal space. History of trauma was encountered in 9.2% of the evaluated cases.

Conclusion: Relatively equal distribution across the three level of endodontic treatment complexity was observed. The prevalence of severe root curvature and severely reduced canal space was relatively low. Previously endodontically treated teeth and teeth with pre-existing extra-coronal restoration formed a considerable proportion of endodontic treatment encountered in general dental practice.

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